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NEW YORK PSYCHOPHYSIOLOGY LAB J L ANDREASSI ET AL.

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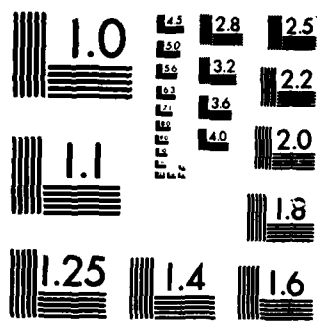
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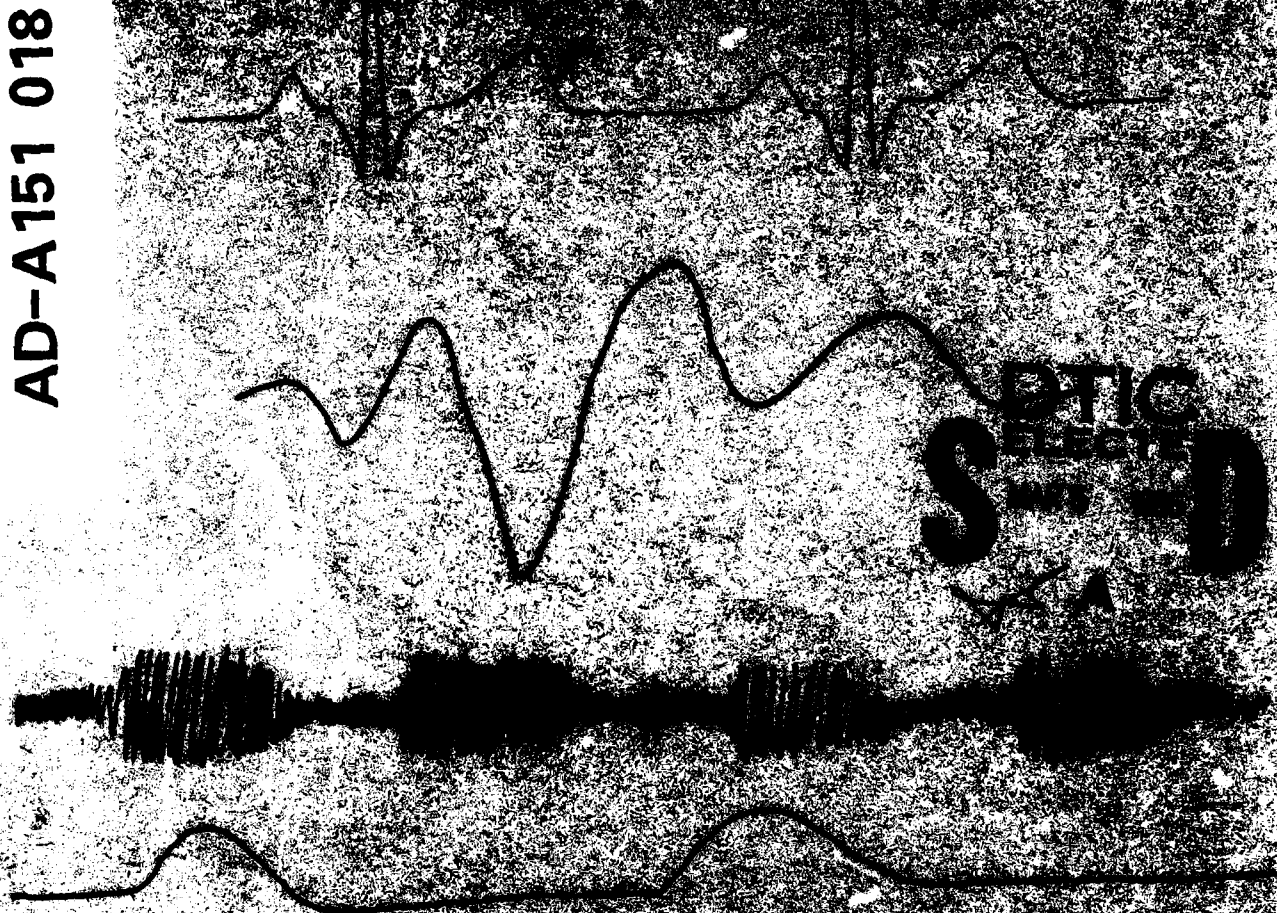
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# Physiological Responses and Information Processing

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Department of Psychology  
Baruch College  
The City University of New York

✓ Psychophysiology Laboratory  
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✓ Baruch College  
The City University of New York

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>This is the first annual report to be completed under Air Force Office of Scientific Research grant AFOSR-83-0304. The report details the background, findings and conclusions of three studies completed in the Psychophysiology Laboratory of Baruch College, City University of New York, over the past twelve months.</p> <p>The first experiment was concerned with the effects of varied frequency of light stimulation upon verbal learning and a number of physiological responses, including: heart rate (HR), electromyogram (EMG), pulse wave velocity (PWV) and</p>		

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skin temperature (ST). The main findings were that HR was sensitive to task difficulty, while EMG was affected by frequency of light stimulation. Another finding was that lower baseline HR was related to better learning performance. The PWV and ST measures were not changed by either learning or light stimuli in any systematic way. There was evidence for varied patterns of physiological response for different individuals as well as some evidence in support of the Law of Initial (LIV), which states that changes in physiological response under task situations are influenced by pre-stimulus levels of physiological activity.

The second study examined the effects of intensity of light stimulation on performance in a short term memory task (Sternberg paradigm) and a variety of physiological measures, including the event-related brain potential (ERP), HR, EMG, PWV, and ST. The major findings were that the endogenous component of the ERP (the P3 response) was delayed in latency with increased memory set size under the condition of no light stimulation. This was attributed to a greater amount of stimulus evaluation time required when subjects had to process larger amounts of information. This conclusion is supported by the finding that reaction time (RT) also increased in a linear fashion with greater information processing demands. An additional observation was the decreased amplitude of the P3 response with larger set sizes. This was attributed to greater uncertainty on the part of subjects when confronted with more information to process which, in turn, led to greater variability in P3 latency, thus contributing to lowered amplitudes. In addition, lower P3 amplitudes were found to be related to longer RTs. The second experiment also provided evidence for an increase in subject's HR with set size, an effect which was probably due to increased cognitive effort under the more difficult conditions. The second study also provided evidence in support of the LIV and subjective response patterning.

In the third study, we focused upon an examination of possible differences between the left and right hemispheres of the brain in processing verbal (words) versus spatial (areal size estimation) materials. To accomplish this, three different words and three rectangle sizes were briefly (40 msec) presented in left and right visual fields. A performance measure was obtained by requiring subjects to provide pre-established synonyms for the words and to judge whether the rectangles were small, medium or large. The measure of brain activity was provided through ERPs recorded from over left and right parietal areas.

Practice sessions for each subject insured at least a 40 percent correct response rate (above chance) prior to actual data collection. It was found that 1) there were no performance or ERP differences for the two hemispheres with the verbal task; 2) the left hemisphere excelled in the spatial task, however, ERPs derived from the two hemispheres did not reflect this difference; 3) size discriminations were more difficult than words and this was reflected in delayed P3 latencies to the rectangles. It was proposed that more difficult discriminations required longer stimulus evaluation time and that this was reflected in delayed P3 response.

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PSYCHOPHYSIOLOGICAL STUDIES I: PERFORMANCE AND PHYSIOLOGICAL RESPONSE IN  
LEARNING, SHORT TERM MEMORY AND DISCRIMINATION TASKS

Prepared By: John L. Andreassi  
and  
N. Mauro Juszcak  
  
Psychophysiology Laboratory  
Baruch College  
City University of New York

For: Air Force Office of Scientific Research  
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The first experiment was concerned with the effects of varied frequency of light stimulation upon verbal learning and a number of physiological responses including: heart rate (HR), electromyogram (EMG), pulse wave velocity (PWV) and skin temperature (ST). The main findings were that HR was sensitive to task difficulty, while EMG was affected by frequency of light stimulation. Another finding was that lower baseline HR was related to better learning performance. The PWV and ST measures were not changed by either learning or light stimuli in any systematic way. There was evidence for varied patterns of physiological response for different individuals as well as some evidence in support of the Law of Initial Values (LIV), which states that changes in physiological response under task situations are influenced by pre-stimulus levels of physiological activity.

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# EXPERIMENT I -- Effects of Varied Frequencies of Light Stimulation on Learning and Physiological Responses

## INTRODUCTION

Light stimulation can affect a variety of physiological responses. For example, it has been reported that color of light stimulation affects duration of alpha desynchronization (Ali, 1972, 1973). The duration of EEG desynchronization was greater for red light as compared to blue. Another form of electrical activity which is sensitive to light stimulation is the event related brain potential (ERP). The visual ERP is known to change with the wavelength or color of the stimulus and intensity of the light (White and Eason, 1966; Perry et al., 1972; Vaughan and Hull, 1965). Electrodermal activity has also been reported to change as a function of color of light stimulation (Nourse and Welsh, 1971; Jacobs and Hustmyer, 1974). In addition, elevations in heart rate have been observed with increases in light intensity (Stone et al., 1974). Thus, even this very brief review indicates that light stimulation can influence the type of physiological response observed.

More relevant to the topic of the present investigation is a study by Zeiner et al. (1972) who studied the effects of high intensity light pulses on the physiological responses of 13 young adult males. The subjects were exposed to a high intensity anti-collision light flashing at a rate of 1.27 Hz. Significant increases occurred in all physiological measures with light stimulation (occipital EEG, skin potential, heart rate, respiration, and eye blinks). In another study, Zeiner and Brecher (1975) found that reaction time to a visual display was significantly

impaired (slower) under conditions of light backscatter vs no backscatter. This latter study did not employ physiological responses as a measure. An abstract of a Russian study (Zhernavkov, 1978) indicated that pilot performance was studied during short-term exposure to intensive light stimulation. The experiments were conducted under both laboratory conditions and in a flight trainer. Performance and physiological measures indicated that high intensity light stimulation produced elevated physiological responses and that repetitive light stimulation can affect physiological response and performance.

The purpose of the present experiment will be to obtain both performance and physiological responses during a learning task under conditions in which the frequency of light stimulation is varied. The range of flash repetition rates will slightly extend those used in previous studies (e.g., Zeiner et al., 1972). It will also investigate the relationship among a number of physiological variables (electromyogram, heart rate, pulse wave velocity, and skin temperature). There are relatively few studies on the effects of light stimulation on both physiological response and performance. Thus, it is hoped that this current study will add information to help fill the void. At this point, before we describe our method, it would be instructive to mention one relatively recent study which has some relevance to our current research. This study by Kanemitsu (1980) investigates the effects of arousal (produced by white noise) on performance level and physiological activity during human learning. One premise was that white noise and task difficulty would serve as physical and cognitive arousers, respectively. Forty subjects were used to test these hypotheses and were randomly assigned to four experimental groups consisting of two noise levels and two levels of task difficulty. There

was a trend for an interaction between physical and cognitive arousers, i.e., the administration of white noise increased performance level under the easy task while it decreased under the difficult task condition. Heart rate increased during rote learning, reflecting its highest arousal level at the recall periods.

#### METHOD

Subjects: Twenty-four students associated with the City University of New York (12 male, 12 female) participated in this study. They ranged in age from 18-32 years. Each subject was administered a vision test for binocular visual acuity (at distance and at near) with a Bausch and Lomb Orthorator. All participants met the criteria for normal visual acuity (corrected to at least 20/25 with glasses).

Apparatus and Procedure: The physiological responses measured were heart rate (HR), pulse wave velocity (PWV), skin temperature (ST), and electromyogram (EMG). The HR and PWV were recorded with a Cyborg BL907 pulse wave velocity monitor. Two pressure sensitive transducers were placed on the left arm, one over the radial artery and the other over the brachial artery. The radial placement measured HR in beats per minute (BPM) with the continuous average switch set at two beats (2 beat average). The HR is displayed digitally on a continuous basis. This procedure also allowed for the recording of PWV. The unit of measurement for PWV is the number of milliseconds it takes for a pulse wave to travel one centimeter. The actual brachial-radial PWV is obtained by multiplying the value read out times the brachial-radial distance for each subject.

The ST measurement was obtained with a Cyborg Thermal P642. Temperature was recorded by two thermistors placed on the volar surface of the distal phalanx of the left hand (middle and index finger) and was displayed as the average of the two thermistors (to .01 degrees Fahrenheit). Electromyogram activity was measured with a Cyborg P303. Measurements (to .1 uV) were made from the skin surface over the flexor digitorum muscle of the left arm. Electrode placement was accomplished by measuring the distance (in cm) between the medial epicondyle of the humerus to the styloid process of the radius. The first electrode was placed at a point one-third the distance from epicondyle to styloid. The second one was placed three cm distally from the center of the first. A third electrode on the forearm served as ground. Resistance between active leads was 5,000 ohms or less as measured by a Grass impedance meter.

The physiological recordings were fed into Cyborg Q700 data accumulators. The data accumulator provided 10 second accumulated averages of the EMG data, and printouts of displayed data for HR, ST, and PWV. The Cyborg Q740 digital printers, under control of the data accumulators, printed these values every 10 seconds.

Subjects were seated in an electrically shielded sound attenuated IAC chamber facing a VR-14 (CRT) with their left arm placed on a table (palm up). They were reminded to keep the arm in this position during the session - 1 to avoid any unnecessary movements. The CRT was mounted outside the chamber window at eye level. A Grass photo-stimulator (PS-2) was positioned on a 30 inch high support in the chamber behind the subject and was faced toward the rear chamber wall.

There were three light stimulation conditions: no light, 1 Hz and 2 Hz, all at intensity setting 1.\* The 1 Hz and 2 Hz conditions were generated by setting the PS-2 to produce the appropriate frequencies. The no light condition was obtained by simply turning off the PS-2. Visual stimuli consisted of three letter sets of nonsense syllables of 0% and 7% association value (Hilgard, 1951). Each three letter combination appeared horizontally at the center of the VR-14 CRT. Timing between presentations was a constant four seconds. A small fixation point (red neon light) was placed 3 mm above the center of the middle character to enable subjects to maintain their line of sight.

Subjects were required to engage in a nonsense syllable learning task under the three experimental conditions. Three Xs or three zeros appeared on the CRT followed by five three letter nonsense syllables. The subject's task was to learn the syllables that followed the Xs (learn) and to count the ones that followed three zeros (watch). When the Xs appeared, they were followed by the list of "learn" syllables which the subjects saw for the first time. When the Xs appeared the second time, subjects had to anticipate the first syllable in the learn list by verbally reporting each letter in their correct order (anticipation method of learning). After the fifth "learn" syllable, the zeros appeared and subjects counted the list of five "watch" syllables. The counting procedure was used in an

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\* The luminance level measured at the PS-2 surface for a steady light was 700 footlamberts. The same measurement for a flashing light at 1 Hz was 100 footlamberts (all readings obtained with a Tektronix J-16 photometer).

attempt to prevent rehearsal of the "learn" syllables during the "watch" periods. The "learn" and "watch" syllables were alternated until each was presented six times. Letters were recited to avoid pronunciation difficulties that subjects might experience with these syllables. Sample lists of "learn" and "watch" syllables appear below. Note that there were six different lists of each presented over the course of the two hour session.

LEARN

XXX  
XAD  
WUQ  
XIP  
YUV  
TOV

WATCH

000  
XUY  
SIJ  
WUB  
YUK  
VAF

Instructions given to subjects were the following:

Three Xs (XXX) or three zeros (000) will briefly appear on the screen followed by five syllables, each appearing one at a time. You are to recite each letter of the syllables that follow the Xs and simply count out loud the ones that follow the zeros, i.e., you are not required to learn the syllables that follow the zeros. Under certain conditions, a light in the room will flash on and off. You are to ignore the light and concentrate on the task. Try to do the best you can. You will be given credit for the number of letters you can correctly anticipate.

The task was illustrated by the experimenter with sample nonsense syllables printed on index cards. Subjects practiced with these cards until they were completely familiar with the task. In addition, subjects were advised not to rehearse the "learn" syllables while counting the "watch" syllables. They were told that rehearsal might produce confusion.

Both lists of learn and watch syllables were repeated six times after their initial presentation. Thus, there were six trials within a given condition. Each condition lasted five minutes. The three light conditions were repeated, resulting in a total of six conditions per session. Thus, for example, if the order was 2 Hz, 0 Hz, 1 Hz for that subject, it was

repeated in the same session. Three minute rest periods followed each conditions. The data accumulator and printer were timed to generate two data averages of the physiological measures within each six trial learn and watch period. Thus, HR, PWV, ST and EMG responses were obtained separately for learn and watch segments over the course of the six trials. Performance was recorded by one of the experimenters who listened to subjects' responses via a Lafayette intercom system. After the last trial, subjects were asked to recall all the syllables that they had learned, in the original order of presentation. This procedure was implemented to determine the degree to which subjects actually learned the syllables. Partial credit was given for a letter of a syllable produced in the correct order.

The HR, PWV, ST and EMG samples were recorded during a five minute baseline period prior to the beginning of the first condition. During this period, the subjects were instructed to relax with their eyes closed and to remain as still as possible. After each experimental condition, subjects were given a three minute rest period in which additional physiological measures were taken. The PS-2 was turned off and subjects were again asked to relax and close their eyes.

The Jenkins Activity Survey was administered to 21 of our subjects. This instrument is designed to identify the degree to which individuals exhibit Type A behavior. An individual with a high score in Type A is characterized by competitive, aggressive, impatient behavior in which he/she is engaged in a struggle to overcome environmental barriers. Those who score low on the scale exhibit a more relaxed life style (Type B).



## RESULTS

Learning Performance: The mean number of letters correctly anticipated was computed for each light stimulation condition, trial and subject. The data were subjected to a three-way analysis of variance (ANOVA) in which the dependent measures were log-transformed to ensure conformity with the assumptions required for parametric statistical analyses. Significant trial,  $F(5/115)=126.5$ ,  $p<.001$ , and subject,  $F(23/46)=6.58$ ,  $p<.001$ , main effects were obtained. The main effect for light was not significant for all six trials. However, when the various light conditions were compared for performance on trial six, there were significant differences (see Figure 1). The steady syllable acquisition over trials is depicted in Figure 1 as well as performance for 0 Hz, 1 Hz and 2 Hz light conditions for trial six. These differences were evaluated by t-tests for correlated data and the 1 Hz condition resulted in better performance than the 0 Hz ( $t=2.26$ ,  $p<.025$ , 23 df) but not the 2 Hz ( $t=0.48$ ,  $p>.05$ , 23 df) condition. The 2 Hz and 0 Hz conditions did not differ ( $t=1.35$ ,  $p>.05$ , 23 df).

Physiological Measures: Separate ANOVAs were performed on the HR, EMG, ST and PWV measures. The main effects were: light stimulation (0 Hz, 1 Hz and 2 Hz); trials (1 through 6); task (learn vs watch) and subjects (1-24). Log transformations of the data were performed prior to ANOVA computations.

Heart Rate Analyses: Heart rate data in BPM were printed out every 10 seconds over the course of baseline, learn, watch and rest periods. The ANOVA revealed a significant learn-watch effect,  $F(1/23)=7.78$ ,  $p<.05$ , in which HR was consistently higher for learn than for watch, under all light stimulation conditions (see Figure 2). In addition, there were

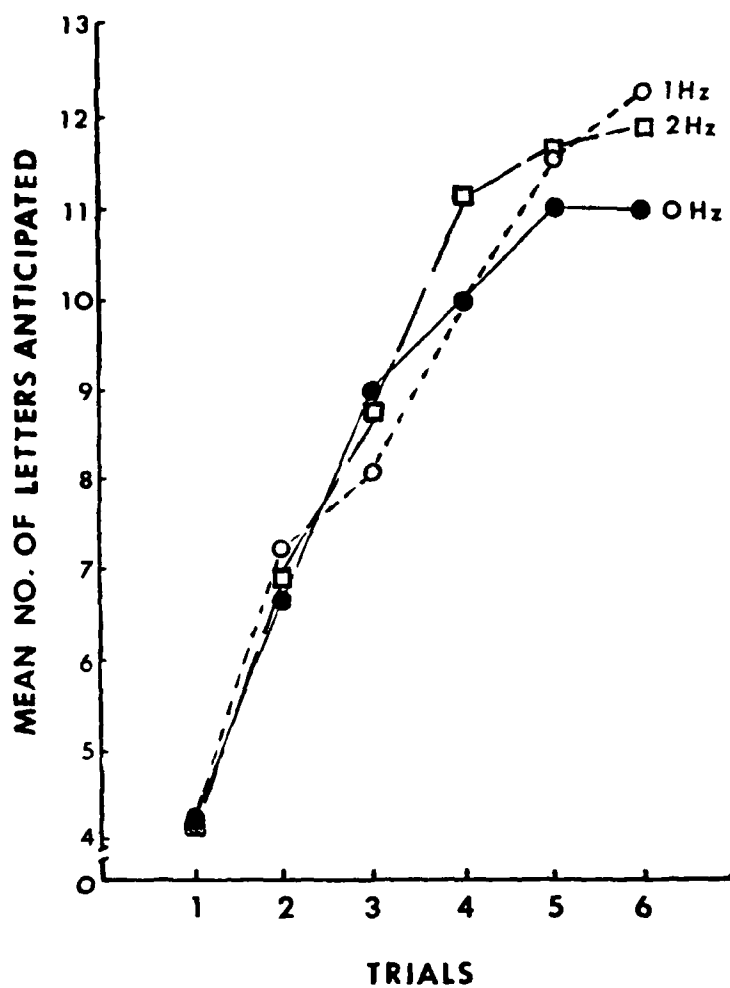


Figure 1 - Mean number of letters correctly anticipated as a function of frequency of light stimulation (N=24).

significant subject effects,  $F(23/24)=56.03$ ,  $p < .001$ , and subject X trial interaction effects,  $F(115/230)=1.48$ ,  $p < .01$ . There was an overall trend towards a decrease in HR over trials. However, when the data were analyzed separately as a function of task, the decrease was more pronounced for the watch as compared to learn situation (see Figure 3). When the extent of decrease was examined by a t-test for correlated data, a significant drop was shown for the watch segment ( $t=4.65$ ,  $p < .001$ , 23 df) but not for learn ( $t=1.45$ ,  $p > .05$ , 23 df).

Pearson correlation coefficients were computed to examine the relationship between the subject's performance and HR (learn, watch). A Pearson correlation coefficient ( $r_p$ ) of  $-.27$  and  $-.26$  for the learn and watch periods, respectively, indicated a negative relationship, but failed to reach the .05 level of significance (22 df). We did find, however, a significant Pearson correlation ( $r_p = -.43$ ,  $p < .05$ , 22 df) between subjects' baseline HR and performance, which suggests that subjects with lower baseline HR performed better than those with relatively high baseline HR. Figure 4 is a scattergram which shows this relationship.

To test the concept of the Law of Initial Values, the HR data were examined with respect to percent change from baseline. Specifically, each subject's baseline HR was subtracted from the measures recorded during the learn and watch segments (combined). This difference was divided by baseline to yield a "percent change from baseline" for each subject. All 24 baseline HR measures were then ranked from lowest to highest to determine the median baseline HR (71.8 BPM). Each subject's percent change was tallied in a four-fold contingency table ( $2 \times 2$ ) according to whether the change showed an increase (+) or decrease (-) and whether the percent change was above or below the median. Our expectations were that if the

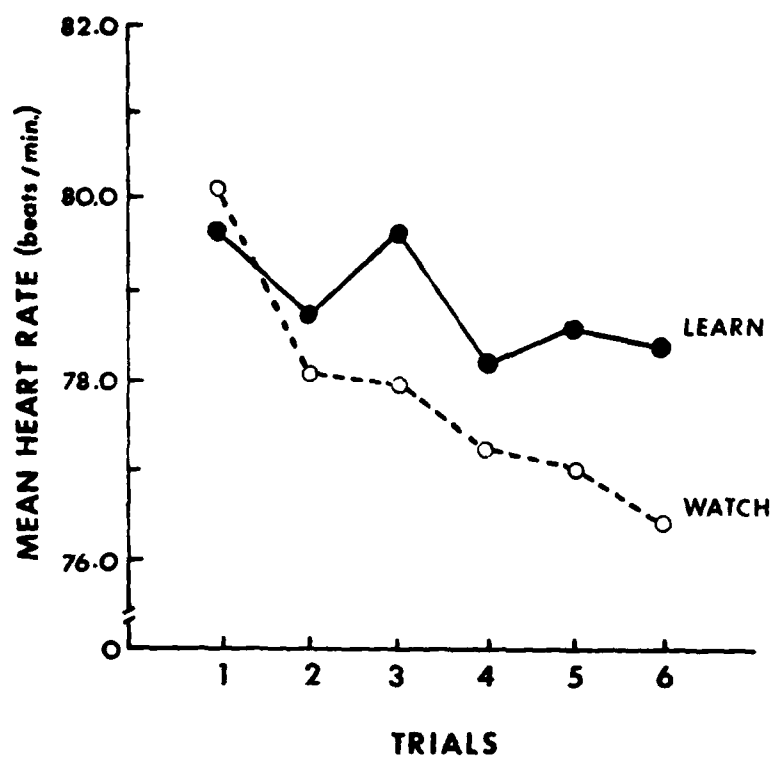


Figure 2 - Mean heart rate, in beats per minute, during "learn" and "watch" periods. Note the steeper drop for the watch condition (N=24).

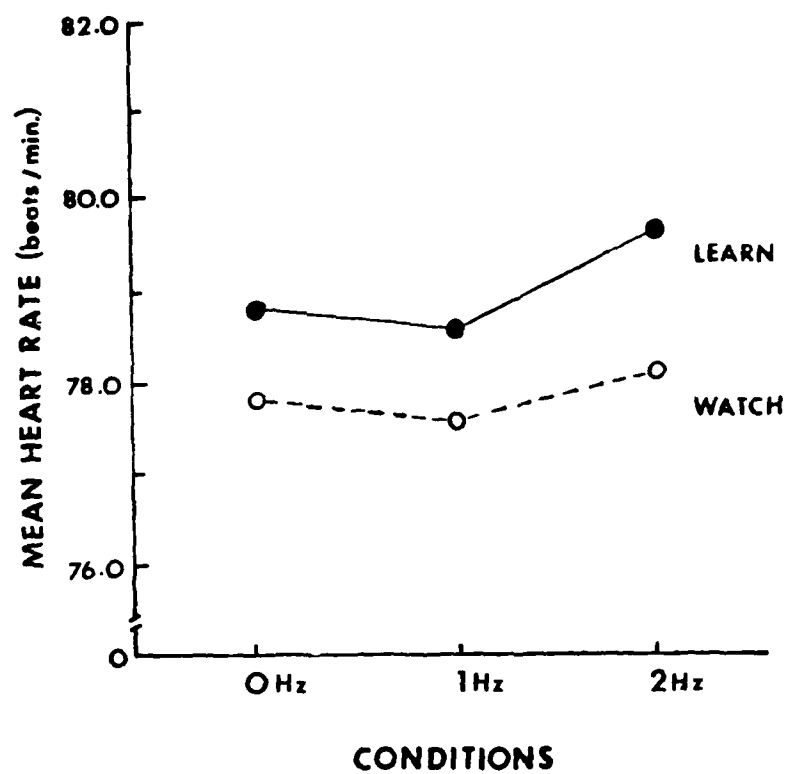


Figure 3 - Mean heart rate as a function of learn and watch under the three conditions (N=24).

LIV held for HR, then subjects with baseline HR below the median would tend to show an increase (+) in percent change from baseline to the learn/watch segment while subjects above the median would tend to show a decrease (-). A chi-square test was conducted to determine if the observed frequencies (tallies) significantly differed from the expected frequencies. The computed chi-square statistic was 2.00, which was non-significant ( $p > .05$ , 1 df).

EMG Analyses: The EMG values were printed out every 10 seconds to the nearest .1 microvolt ( $\mu V$ ). The ANOVA for EMG data revealed a significant light stimulation effect,  $F(92/46)=4.95$ ,  $p < .05$  as well as a significant subject effect,  $F(23/46)=34.25$ ,  $p < .01$ . This light effect was further examined with t-tests for correlated data and resulted in a finding of significantly higher EMG with higher frequencies of light stimulation. For example, the 2 Hz condition resulted in significantly higher EMG levels than the 0 Hz condition ( $t=2.45$ ,  $p < .025$ , 23 df). In addition, the 1 Hz condition produced significantly higher EMG activity than the 0 Hz condition ( $t=1.75$ ,  $p < .05$ , 23 df). There was a non-significant trend in which the 2 Hz condition produced greater EMG activity than the 1 Hz condition. These differences are illustrated in Figure 5, which shows EMG level as a function of trial and light stimulation condition. Note that with the 2 Hz condition, EMG activity increased considerably from trial 1 to 6. A t-test for correlated data which compared EMG levels in trial one with those in trial six was found to be significant ( $t=2.75$ ,  $p < .02$ , 23 df). Figure 5 also shows that there was little change in EMG activity between trials one and six with the 0 Hz and 1 Hz conditions (0 Hz:  $t=.06$ ,  $p > .05$ , 23 df; 1 Hz:  $t=.97$ ,  $p > .05$ , 23 df, t-test for correlated data). The EMG data do not distinguish between the learn and watch situations as

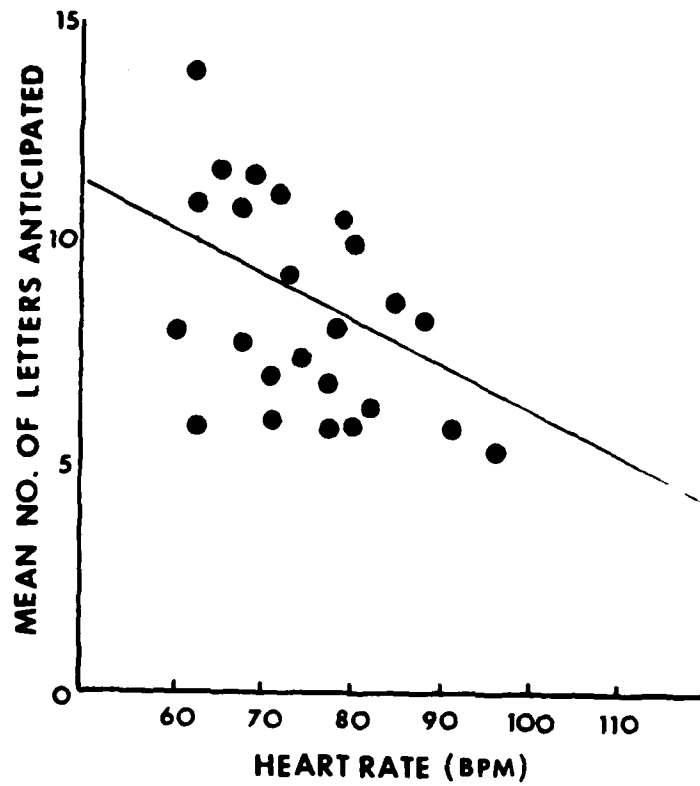


Figure 4 - Scatter diagram illustrating relationship between performance and baseline heart rate. Each plotted point represents one subject. Note the inverse relationship.

does HR. Significant two-way interactions were found for EMG data with respect to subjects X light,  $F(46/230)=7.33$ ,  $p < .01$ .

The Pearson correlations conducted on the EMG data recorded separately during the learn, watch and baseline periods indicated very little relationship between EMG and performance (learn:  $r_p = +.02$ ; watch:  $r_p = +.03$ ; baseline:  $r_p = -.05$ , 23 df,  $p > .05$  for all). The method used for computing the percent change from baseline EMG and distributions of the percent change according to whether subjects were above or below the median (1.72 uV) was used again. The chi-square test which examined the distribution of these percent changes was non-significant ( $\chi^2=1.02$ ,  $p > .05$ , 1 df).

Skin Temperature: Skin temperature (ST) values were recorded to the nearest .01 degree Fahrenheit. The ANOVA for ST showed a significant effect for subjects,  $F(23/46)=98.39$ ,  $p < .001$ . Although the trial main effect was not significant ( $p > .05$ ), there was a regular, continuous drop in ST as trials progressed. It was observed during experimental trials that ST would immediately begin to rise after the last trial in the segment, and when the subject was instructed to "rest." There were higher (but non-significant) ST levels for 2 Hz than 1 Hz, and higher levels for 0 Hz than 1 Hz. Significant two-way interactions were observed for subjects X light,  $F(46/230)=93.09$ ,  $p < .01$ .

With regard to possible relationships between ST and performance, the Pearson correlations were slightly positive:  $+.12$  (non-significant). Thus, there was no relationship between this physiological variable and performance.

The question as to whether the LIV concept would hold for ST was examined with the chi-square statistic. The relative distribution of the percent increase or decrease above and below the median was non-significant ( $\chi^2=1.54$ ,  $p > .05$ , 1 df).



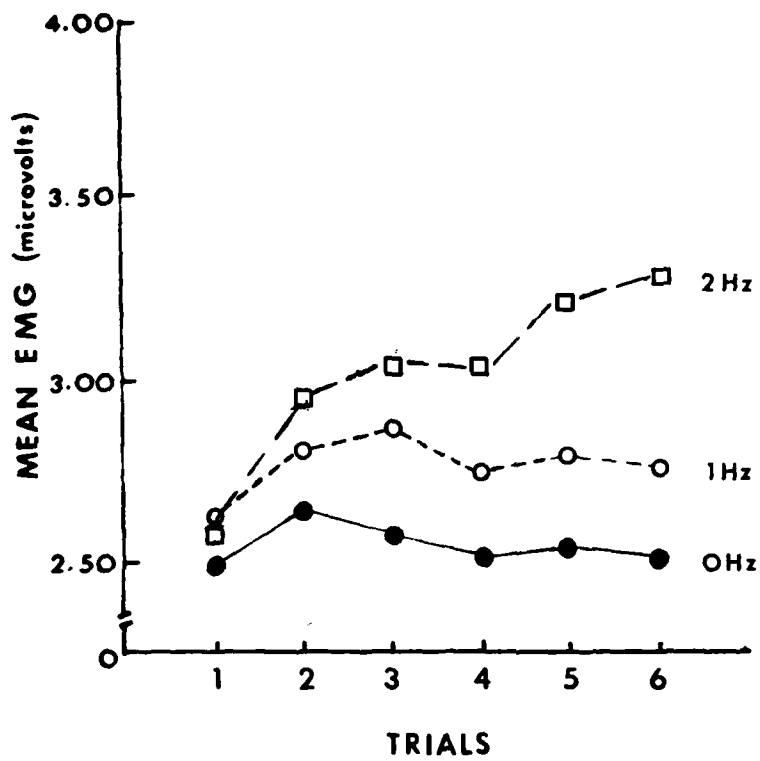


Figure 5 - Effects of different frequencies of light stimulation upon EMG level over trials 1 - 6 (N=24). Note the higher EMG level produced under 2 Hz stimulation.

Pulse Wave Velocity: This measure was calibrated to print out in centimeters traveled per second. The ANOVA for PWV showed significant trial ( $F(5/115)=3.60$ ,  $p<.01$ ) and subject,  $F(23/46)=17.77$ ,  $p<.01$  effects. The trial effect is shown in Figure 6. The figure shows an increase in PWV from trials one through three and then a slight rise or stability for trial four (depending on light condition) and a decrease for trials five and six. In general, there is an overall non-significant trend for higher PWV with higher frequency light stimulation. There was little PWV difference for the learn vs watch segments. In addition, the Pearson correlation coefficients between PWV and performance were  $+.19$ ,  $+.18$  and  $-.02$  for learn, watch and baseline, respectively ( $p>.05$  for all three). With regard to PWV change from baseline, the computed  $X^2$  was non-significant ( $2.80$ ,  $p>.05$ , 1 df) indicating that the observed distribution of percent increase and decrease from baseline for PWV did not differ from the expected distribution.

Response Patterning: In an attempt to determine individual patterning of response under various conditions, a series of bar charts were devised. We compared individual mean resting measures of the four physiological responses relative to the group baseline mean for those responses. Thus, we examined each individual's resting level with that of the group. The differences in pattern were immediately apparent. For example, subject #2 showed a pattern in which HR and EMG were below the mean, while PWV and ST were above. This contrasts with subject #11 who showed HR, EMG and ST levels which were above the mean and PWV which was below the group baseline mean. The pattern of response for each of the 24 subjects under the learn segment of the experiment was also examined. Subject #1 showed a HR response that was below the baseline mean, and ST, EMG and PWV that

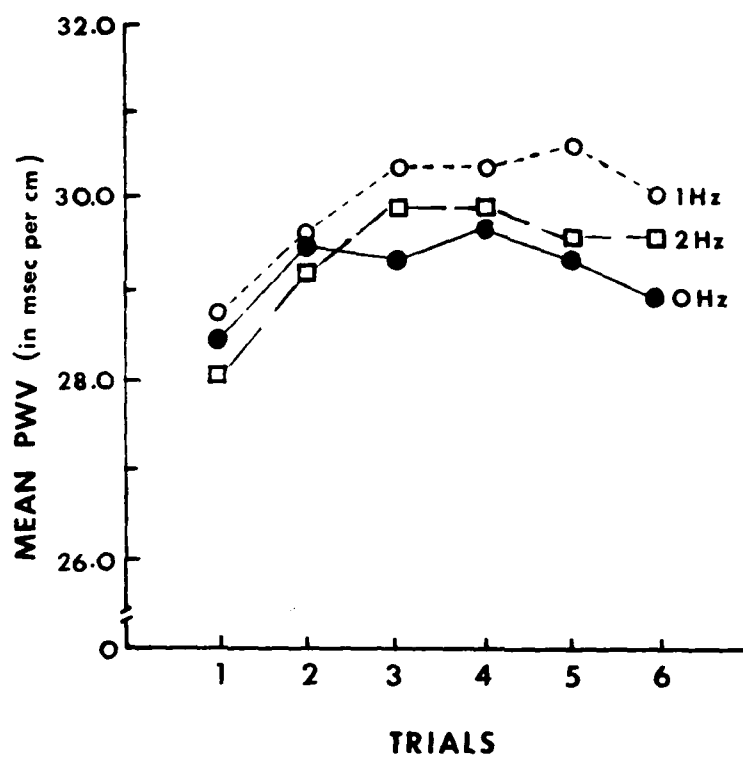


Figure 6 - Mean pulse wave velocity as a function of light stimulation over trials 1 - 6 (N=24).

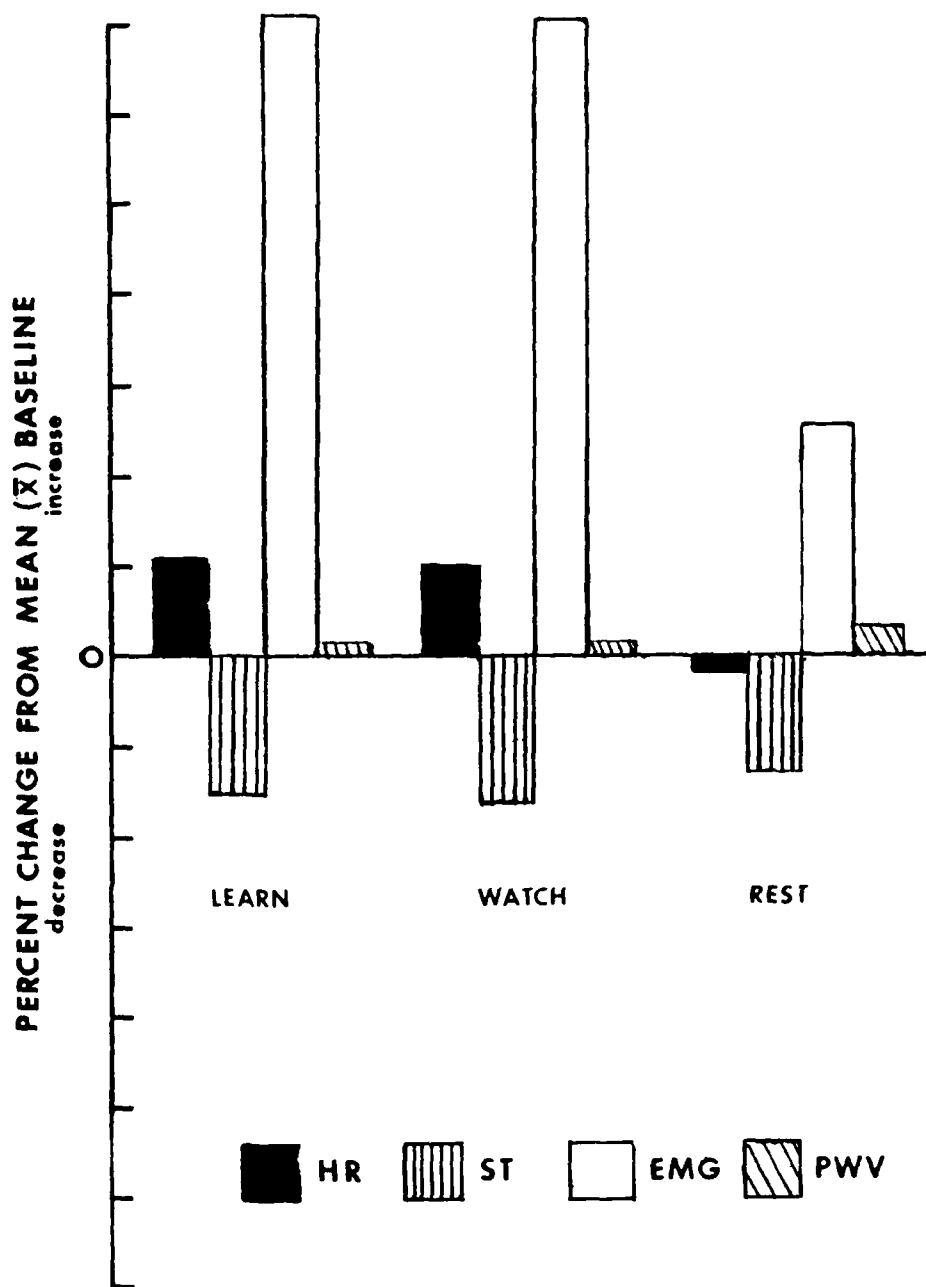


Figure 7 - Patterning of response of various physiological variables under learn, watch and rest conditions (N=24).

were above. Subject #11, however, showed HR and EMG activity which were above the mean and ST and PWV that were below.

In Figure 7 we have plotted the percent change in physiological response relative to the mean baseline response for the group. This shows the degree of response under different segments of the experiment and revealed little change from baseline for all measures under "rest," i.e., there were increases in EMG and PWV, and decreases in HR and ST. More substantial changes occurred both under learn and watch conditions, with slightly larger HR and EMG increases under the learn segment. The ST and PWV measures are almost identical under watch and learn conditions.

The 21 subjects who completed the Jenkins Activity Survey for the purpose of detecting Type A behavior patterns showed a range of scores which placed them in the first to 80th percentile. We found that seven individuals scored at the 50th percentile or above and 14 scored below the 50th percentile. The percent increase in HR from resting to learning conditions did not differentiate the two groups. However, there was a slight difference in resting HR over the six rest periods administered over the course of the experimental session. Namely, the higher Type A individuals tended to show an increase in HR from the first to the last rest period (71%) while the lower scorers on the Type A scale tended to show a decrease in resting HR (57%) from the initial rest period to the last.

#### DISCUSSION

The relationship between light stimulation condition and learning performance on trial six is instructive in that the 1 Hz flashing light was related to the best performance. That is, learning was more efficient with

1 Hz stimulation than with either 2 Hz or 0 Hz. This result would be predicted by activation theory which says that moderate levels of external stimulation result in optimal performance, while higher or zero levels are related to less than optimal performance. This is an interesting finding and we shall examine it again to see how the different levels of light stimulation also affected physiological response.

The light stimulation had different effects on the physiological variables measured and these effects were often complex. For example, the effect of 2 Hz light stimulation was to increase levels of EMG over the level recorded with either 0 Hz or 1 Hz stimulation. There was an insignificant trend for HR to be slightly higher with 2 Hz of stimulation than with either 0 Hz or 1 Hz. In general, the effect of light stimulation was to increase level of physiological activation, but significantly only for EMG. These results are, in general, similar to those of Lovallo and Zeiner (1972).

Heart rate proved to be the only physiological measure affected significantly by the task variables of learn vs watch, i.e., it was higher during the learn segment of the task. The role of cardiac activity change is very important in the intake-rejection hypothesis of the Laceys (1967, 1974). The "rejection" portion of the hypothesis concerns elevations of HR which, through central feedback mechanisms, make the organism less sensitive to potentially distracting stimuli, thus enabling greater attention to the problem at hand, in this present case, learning of nonsense syllables. It will be recalled that baroreceptors located in the carotid arteries signal changes in heart rate to brain stem mechanisms that then produce HR and blood pressure attenuation in cases of increase, and enhancement in those instances where HR or blood pressure have decreased. In addition, brain

activity (including cortical) is increased in cases of cardiac deceleration and decreased when cardiac acceleration occurs (Walker and Sandman, 1982; Walker and Walker, 1983).

The elevated HR for learn vs watch trials continued over the six trials of each condition. When HR on trials one and six were compared, there was a significant drop evidenced for the watch segment, but not for the learn segment, even though the HR was similar on trial one for both learn and watch. Thus, subjects maintained HR at a relatively elevated level over the learn segments of the condition, but showed a relaxation when not required to engage in more elaborate processing of the stimuli (watch and count).

When performance was examined as a function of light stimulation condition, trial six showed a pattern consistent with activation theory, i.e., best learning performance with the moderate level of stimulation (1 Hz). The EMG data parallel this somewhat, since over trials one through six, 2 Hz produced the highest EMG levels, 1 Hz produced medium levels and 0 Hz the lowest. The significant differences were between 2 Hz and 0 Hz. None of the other physiological measures evidenced this differential effect of light stimulation on recorded activity levels. It should be pointed out that activation theory has received much of its support from studies in which muscle activity (either induced or allowed to vary naturally with task demands) was varied (see Duffy, 1972; Andreassi, 1980, chapter 15).

Suggestive relationships were found for HR and performance, as revealed in the correlation coefficient (the coefficient for PWV, EMG, and ST indicated little or no relationship). The relation observed suggested that subjects who were more relaxed performed better. We do not believe that lower HR, for example, resulted in better performance, but, instead, that

it may reflect a combination of factors concerning subjects who performed better in the learning task; for example, 1) that they are more psychologically relaxed persons than those individuals who showed more radically elevated cardiac activity and 2) those who performed better are more proficient learners to begin with and are not as threatened by the task as are the less proficient persons.

Response patterning was demonstrated since the various subjects showed individual patterns of baseline level and physiological response during task performance. Some degree of directional fractionation of response was shown since PWV was below the baseline mean under learn and watch, while HR, EMG, and ST were above the mean. Under resting conditions, HR and PWV were both below baseline mean, while EMG and ST were above. Directional fractionation was described by Lacey et al (1963) to denote the type of patterning of response in which one physiological variable shows an increase and another a decrease in level, depending on task conditions.

Law of Initial Value: The LIV was first described by Wilder (1931, 1957). The law states that the degree of physiological change observed during a task is dependent upon pre-task level of that activity. Thus, for example, if physiological activity is at a high initial level, then task related changes may be evidenced as only a slight increase, or even a decrease in level. This is in contrast to a situation which results in large task-related increases or decreases due to an initially very low or high level of physiological activity. We observed a non-significant trend in which subjects with relatively low baseline (pre-task) activity evidenced greater task-related increases than subjects with high baseline levels. For example, 11 out of the 12 subjects with high baseline HR had increases. When subjects with low and high baseline levels are considered as separate



groups, the low baseline group showed on the average a task-related HR increase of 9% while the high baseline group had an increase of 4%. The PWV and EMG data paralleled this trend. Namely, 8 of 12 subjects with low PWV pre-task levels evidenced task related increases, but only 3 of 12 subjects with high PWV pre-task levels showed an increase. There were also differences in percent increase between the low and high baseline PWV group, i.e., the high baseline group showed no change in PWV activity, while the low baseline group showed an overall increase of 10%. The task-induced increase in EMG activity was striking with the low baseline group. Thus, there is some indication that the LIV applies to HR, PWV and EMG activity. What is particularly interesting is the very small difference in task-related ST decreases between the low and high baseline group. That is, the low ST group evidenced an overall 8% decrease while engaged in the task. The high ST group showed a 9% decrease. An examination of each subject's percent change from baseline revealed that 9 of the 12 subjects with high baseline ST measures had lower ST levels during the task, while only 5 of the 12 subjects from the low baseline ST group evidenced lower ST. Taken together, it appears that HR, PWV, and EMG are subject to the effects of pre-stimulus levels (i.e., baseline) while ST is not. This observation is consistent with the findings of Hord, et al. (1964) who found that LIV operated for HR but not ST.

The subjects were not specifically selected with regard to Type A scores and there were very few persons with high (above 75th percentile) or low (below 25th percentile) scores (two and five, respectively).

EXPERIMENT II -- Varied Intensities of Light Intensity Effects on  
Sternberg Task Performance and Physiological Response

INTRODUCTION

In this experiment, our object was to examine the effects of light stimulation on performance and physiological responses during a memory scanning task. Instead of varying light frequency, we varied intensity. The memory task chosen was that devised by Sternberg (1966, 1967) and involves having subjects respond to presented items (targets) by indicating whether they do or do not belong to an original set of memorized items. The level of task difficulty can be manipulated by requiring individuals to memorize longer series of symbols or numbers. Reaction time has been found to increase linearly as a function of the sequence length (Sternberg, 1966). Sternberg's original purpose in using the paradigm was to study the retrieval of information from short-term memory. The supposition is that the task described requires the use of information stored in memory and that reaction time can allow an analysis of the process by which information is retrieved.

The Sternberg paradigm has proven useful to psychophysiologicalists interested in event related potentials (ERP) and memory scanning performance and, in particular, the relationship between P300 latency and reaction time (RT). The P300 is that now well-known ERP component which occurs with the detection or discrimination of some task relevant stimulus. The "P300" label for this brain response originally derived from the finding that it occurred approximately 300 msec after the occurrence of some relevant stimulus (Sutton et al., 1965). However, a large variety of experimental

paradigms entailing a wide range of tasks have been employed since the initial discovery of P300, and its latency has been found to vary between 250 msec post-stimulus to almost 1000 msec, depending on task difficulty or complexity of stimulus evaluation (Donchin, 1978). In our current experiment, we measured other physiological responses in addition to the ERP. These include heart rate (HR), electromyogram (EMG), skin temperature (ST), electrooculogram (EOG) and pulse wave velocity (PWV).

Some earlier ERP investigations which have used the Sternberg task are those of Adam and Collins (1978), Ford et al. (1979) and Gomer et al. (1976). In general, P300 latency and RT increased linearly with greater numbers of items in the memory set, but the slope of the function was steeper for RT (about 25 msec per item). Hillyard and Kutas (1983) are of the opinion that the close correspondence between P300 latency and stimulus evaluation time argues for the superiority of P300 latency over RT as a measure of memory scanning.

In a study by Ford et al. (1979), P300 latency and RT were evaluated in a Sternberg paradigm to compare short-term memory processes in young and elderly individuals. The elderly were slower in RT to probe stimuli and evidenced a steeper increasing RT slope as a function of memory set size than did young subjects. Their P300 latencies, however, were only slightly longer than younger persons and showed similar slopes, indicating that the two age groups compared the probe with memory items at the same rate. The difference between the groups was in response speed rather than in short-term memory processes. In a related study, Podlesny and Dustman (1982) examined the relationship between physiological response and reaction time in healthy young, middle-aged, and elderly males (mean ages 24, 45, and 71 years). These researchers noticed age reductions in P3 amplitude and

heart rate deceleration, but no age effects on P3 latency. The P3 amplitude and heart rate deceleration were most strongly correlated with the choice reaction time among younger subjects. The results suggested that heart rate and P3 responses may reflect physiological processes related to the slower reaction times of healthy elderly persons.

In 1983, Polich et al. conducted a study to see whether P300 latency would correlate with digit span performance. They used a total of 93 neurologically normal subjects, aged between 5 to 87 years with approximately equal numbers in each decade. The event related potential to rare and frequent tones was obtained and the typical P300 complex appeared with the rare tones but not the frequent ones. The authors also divided the P300 responses into P3a and P3b. After the ERP data were obtained, memory capacity was determined with the digit span subtest of the Wechsler Adult Intelligence Scale. Both the digits forward and digits backward components of the task were used. Correlations between the P3 latency measures and memory scores support the suggestion that latency of P300 is related to memory capacity in normal subjects. The authors point out that the implications of human depth electrode recordings, animal studies, and clinical observation suggest that P300 may be initiated in brain sites related to memory operations, i.e., hippocampus and amygdala. The correlation between P300 latency and digit span performance in normal subjects is consistent with this hypothesis. The authors suggest further that P300 latency reflects an individual's capacity to retain recently encoded information for comparison with the new incoming information. If an individual's capacity to maintain a mental representation is diminished due to brain disease or degraded experimentally, the accessibility of previously stored information would be retarded, thereby causing slower internal context changes and prolonged P300 latencies.

Most of the studies reviewed up to this point have concerned the relationship between ERPs and cognitive activity. We will now consider some investigations which have examined cognitive activity along with other physiological variables. For example, heart rate changes during recall and recognition tasks were related to memory load and performance by Jennings and Hall (1980). Twenty volunteers performed a recognition task with memory set size varying between 5 and 10 items. The task was divided into input, retain and test periods. Consistent heart rate changes showed a deceleration prior to each task period which was followed by acceleration. Heart rate was not influenced by memory load, but did show a small but consistent relationship to performance. In both recall and recognition experiments, great acceleration in the retain period was associated with more accurate memory performance. During information input, degree of heart rate acceleration appeared related to recognition performance. The authors interpret the results as being consistent with the suggestion that heart rate deceleration may indicate the availability of processing capacity for new information, while cardiac acceleration may indicate the inaccessibility of capacity.

Lindholm et al. (1979) measured heart rate, skin conductance, eye movement, and cortical evoked response as measures of attention and arousal. Subjects performed both choice reaction time and letter matching tasks. They report that for choice reaction time, faster responses were associated with increased measures of arousal as indicated by heart rate, skin conductance, and evoked potential amplitude. The cortical evoked potential varied systematically with task difficulty and reaction time, i.e., simple decisions evoked short latency, low amplitude ERPs, while more difficult ones produced longer latency, higher amplitude ERPs. The authors conclude

that heart rate and skin conductance measures of arousal reflected generally the degree of subject involvement in the task. The event related potential data varied reliably with task difficulty and performance.

Cardiovascular response and heart rate reactivity were studied during a reaction time task in which winning money was either easy, difficult, or impossible (Light and Obrist, 1983). The impossible condition resulted in reduced responsivity, i.e., a longer pre-ejection period (PEP) and pulse transit time (PTT) and greater decreases in systolic and diastolic blood pressure. Subjects reported trying less hard on the impossible as compared to the difficult or easy condition. Subjects who showed the greatest heart rate increases at onset of the task maintained higher heart rate and showed higher systolic blood pressure and shorter PEP, PTT, and left ventricular ejection time than low heart rate reactives. These differences were less pronounced at the end of the task. High and low heart rate reactives did not differ in measures of behavioral traits, such as Type A (Jenkins Survey), suppressed hostility or active coping as the preferred coping style. Those persons with extreme scores indicating suppressed hostility did show elevated heart rate and systolic blood pressure during both relaxation and during the task.

A consideration of this brief literature review and a number of concepts in psychophysiology suggest several hypotheses. Namely, it is proposed that:

1. Reaction times and P3 latencies will be longer as memory set size increase (Gomer et al., 1976).
2. P3 amplitude will decrease with larger memory set size (Gomer et al., 1976).

3. Pre-stimulus (baseline) levels will be related to "task" levels of physiological response for HR, PWV, ST, and EMG (Law of Initial Values).

#### METHOD

Subjects: The subjects were 27 (12 males and 15 female) students associated with the City University of New York. They ranged in age from 18 to 30 years. Each subject was administered a vision test for binocular visual acuity (at distance and at near) with a Bausch and Lomb Orthorator. All participants met the criteria for normal visual acuity (corrected to at least 20/25 with glasses).

Apparatus and Procedure: Subjects were seated in an electrically shielded sound attenuated IAC chamber while electroencephalogram (EEG), heart rate (HR), pulse wave velocity (PWV), skin temperature (ST), electromyogram (EMG) and electrooculogram (EOG) were recorded. The EEG was recorded from  $P_z$  and  $C_z$  (Ten-Twenty System, Jasper, 1958) with Grass silver cup electrodes referenced to a silver cup electrode on the subject's left ear lobe. A Beckman Type RM Dynograph was used to record the EEG and a 9806 coupler of the Dynograph conditioned the EEG signal (bandpass set at 0.5 to 32 Hz). A Mnemotron Computer of Average Transients (CAT 1000) under program control of a PDP 8/E computer obtained EEG samples of 500 msec duration following presentations of the stimulus to the subject. The resultant summated visual ERP trace was plotted on a Hewlett Packard X-Y plotter.

The HR and PWV were recorded with a Cyborg LB907 pulse wave velocity monitor as described in Experiment I.

The ST and EMG measurements were also measured as described in Experiment I. The physiological recordings (i.e., HR, PWV, ST, and EMG)

were fed into a Cyborg Q700 data accumulator and a digital printer. The data accumulator provided 10 second accumulated averages of EMG, and print outs of displayed data for HR, ST and PWV.

Eyeblinks and eye movements (EOG) were recorded with a two-channel eye movement monitor (Washington University resetting differential amplifiers) and were measured by placing two Beckman biominature electrodes above and below the left eye. The resultant EOG was displayed continuously on a voltmeter in the Washington University apparatus. Any visual ERP traces suspected of eye movement contamination were discarded.

The visual stimuli (1 cm digits) were displayed on a Digital Equipment Corporation VR-14 CRT which was mounted at the subject's eye level outside the chamber at a distance of 70.6 cm. This produced a visual angle of 49 minutes of arc. The VR-14 was controlled by the PDP 8/E to deliver the stimuli at specific locations on the CRT. The disappearance of the stimuli was virtually immediate (50 usec) with the brief persistence P24 phosphor specially installed in the VR-14.

Subjects were seated in the IAC chamber facing the CRT. Their left arms were placed palm up on a table. They were reminded to keep their arms in this position during the session and to avoid any unnecessary movements. Subjects were instructed to place their right index finger over a telegraph key. The position of the key was adjustable to allow for differences in arm length. A chin rest allowed subjects to maintain their heads in a stable position while viewing the CRT. A Grass photometer (PS2) was mounted on a 30 in. high support in the chamber behind the subject and faced toward the rear chamber wall.

There were three conditions: Intensity 1, Intensity 4, and zero light. The light conditions were generated by setting the PS2 to produce the



appropriate intensity at 1 Hz. The light intensity settings produced luminance levels of 100 footlamberts (setting 1) and 400 footlamberts (setting 4). These values were measured at the PS2 surface for a steady light by using a Tektronix J-16 photometer. All subjects reported that at intensity setting 4 the flickering light was brighter than the light at intensity setting 1.

In the Sternberg task used, subjects were given sets of 1, 2, or 4 numbers to memorize (response set). Single "target" numbers were then presented for 40 msec on the VR-14. Subjects were asked to respond whenever a digit from the original response set (positive set) was presented. The response consisted of pressing a telegraph key as quickly as possible without making errors. They were asked not to respond if the number did not appear in the original memorized set (negative set).

Prior to a given light condition, the subject was given the number(s) to memorize. Afterwards, the door of the chamber was closed and 24 single digits were presented, one at a time, at varying interstimulus intervals (between 2 and 4 sec). One half of the numbers were members of the response set. The presentation of each number triggered the CAT to take EEG samples and also initiated a digital reaction timer. Reaction times were recorded by the experimenter to the nearest msec. Visual ERPs were based on averaged brain responses to all 24 numbers.

The instructions to subjects were as follows:

The purpose of this study is to measure physiological activity (skin temperature, heart, muscle, eye movements, and brain activity) while you perform a simple memory task. You will be asked to memorize some numbers. Later, a series of numbers will briefly appear on the screen, one at a time. Your task is to press a key if the number on the screen is a member of the set of numbers you have memorized. Do not respond if the number is not part of the memorized set. Respond as quickly as you can, but try not to make any errors.

Under certain conditions, a light in the room will flash on and off. You are to ignore the light and concentrate on the task.

You must keep your left arm and fingers still at all times, since movements will interfere with our recordings. Also, you must not blink or move your eyes during and immediately following presentation of the numbers.

A small fixation point (red neon light) has been placed above the position where the numbers will appear. This will enable you to maintain your line of sight. Look, do not stare.

Before we begin, close your eyes and relax, breathe deeply and maintain a blank mind. This procedure will allow us to make sure we are getting good recordings. Do you have any questions?

Baseline recordings of HR, PWV, ST, and EMG were obtained over a five minute period. All baseline measures were taken with eyes closed and no light stimulation. Immediately after the baseline recordings, the experiment was started. After all experimental trials were completed, a three minute "rest" period was obtained under similar conditions to baseline recordings. Subsequent to data collection, subjects completed a Jenkins Activity Survey to determine their degree of Type A behavior as defined in the scale. The Jenkins results indicated that seven of our subjects were high in Type A behavior (75th percentile or above) and six were low (25th percentile and below).

With three light conditions and three set sizes, there were a total of nine experimental conditions. A given set was never repeated. After each condition, a string of 24 numbers were presented on the screen at fixed 2 second intervals. Twenty-six subjects were instructed to simply watch the numbers, i.e., they were not required to respond to any of the numbers. Visual ERPs were obtained during this "watch" period. These data were collected to provide control data regarding the effects of task engagement vs merely watching the digits upon the visual ERP.

The nine experimental conditions were counterbalanced using a Greco-Latin square design. This resulted in a total of 18 ERP traces from  $P_z$  and  $C_z$  during the task segments and 18 ERPs during the watch segments.

## RESULTS

Reaction Time: The RT data were log-transformed prior to ANOVA computations. A three-way ANOVA examined subjects, light intensity and set size as main effects and also examined their interactions. Significant main effects were also observed (for subjects,  $F=12.19$  (26/52),  $p < .01$  and for set size,  $F=58.39$  (2/4),  $p < .01$ ). The mean RT for memory set sizes of one, two and four was 564, 600 and 647 msec, respectively. The Newman-Keuls multiple comparison test (Winer, 1971) revealed that each of these RT values was significantly different from the others ( $p < .01$ ).

Event-Related Potentials: Through analysis of the ERP traces of each subject, several major ERP components emerged. These were identified in the following manner with respect to latencies and amplitudes:

Latencies -- Two individual components were identified: N150, and P377. The N150 component was measured from the peak of a large negative wave appearing between 100 and 170 msec post-stimulus in the 500 msec sample. The component termed P377 was measured from a second peak appearing between 330 and 425 msec post-stimulus. If the peaks appeared more as a plateau, the midpoint of the plateau was taken as the latency measurement.

Amplitudes -- One component was analyzed with regard to amplitude. The measurement in microvolts ( $\mu V$ ) was taken as the vertical distance from the peak of N150 to the peak of P377.

Representative visual ERP traces of two subjects are illustrated in Figure 1. The traces were obtained from  $C_z$  and  $P_z$  recording sites for the nine experimental conditions. The small vertical bars indicate the N150 and P377 components. They formed the basis for the P3 amplitude, which was measured from the peak of N150 to the peak of P377.

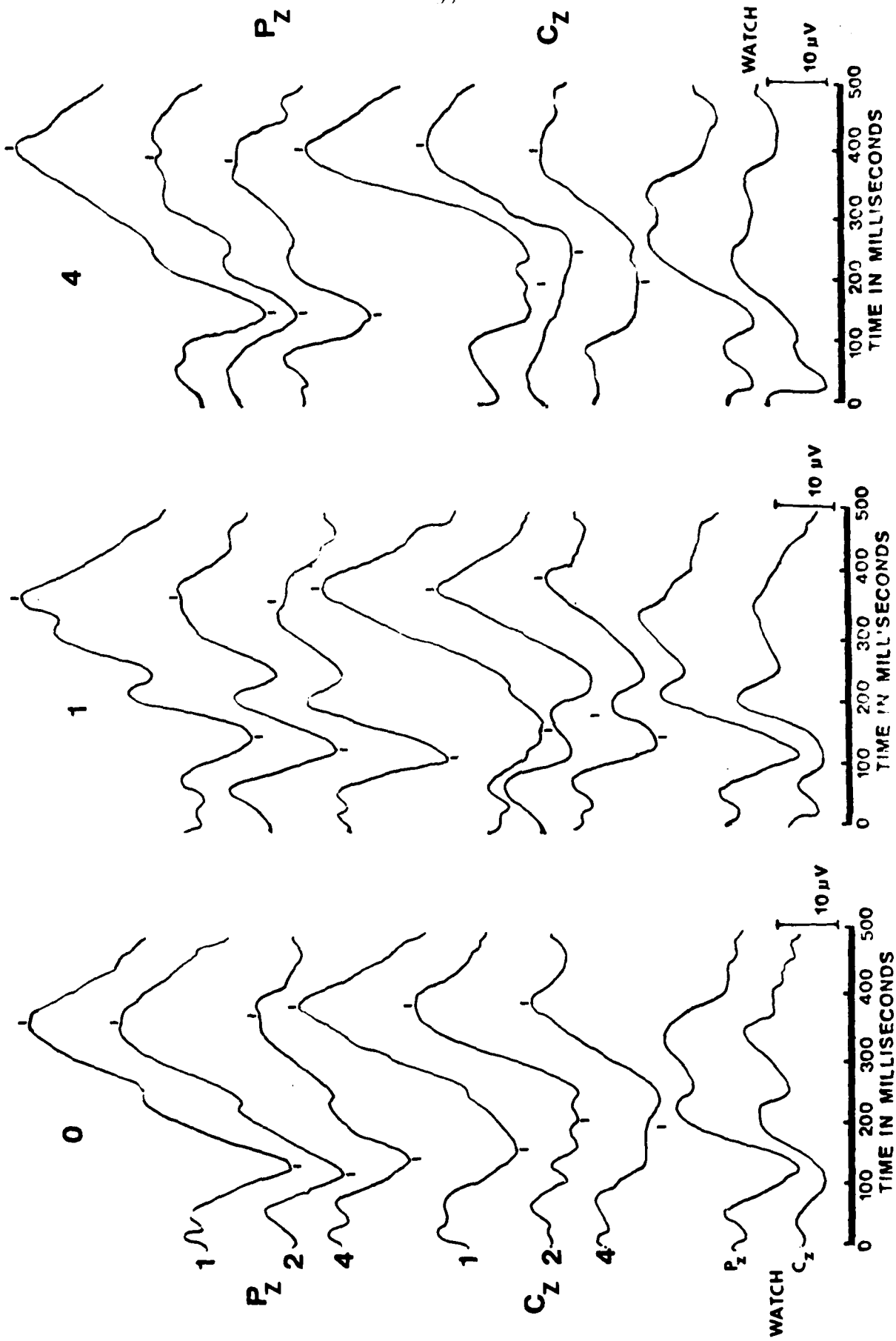


Figure 1 - Visual ERPs of J.R. recorded from Pz and Cz under task and watch conditions. Numbers at top indicate light intensity; numbers at left side indicate set size. Negativity is downward.

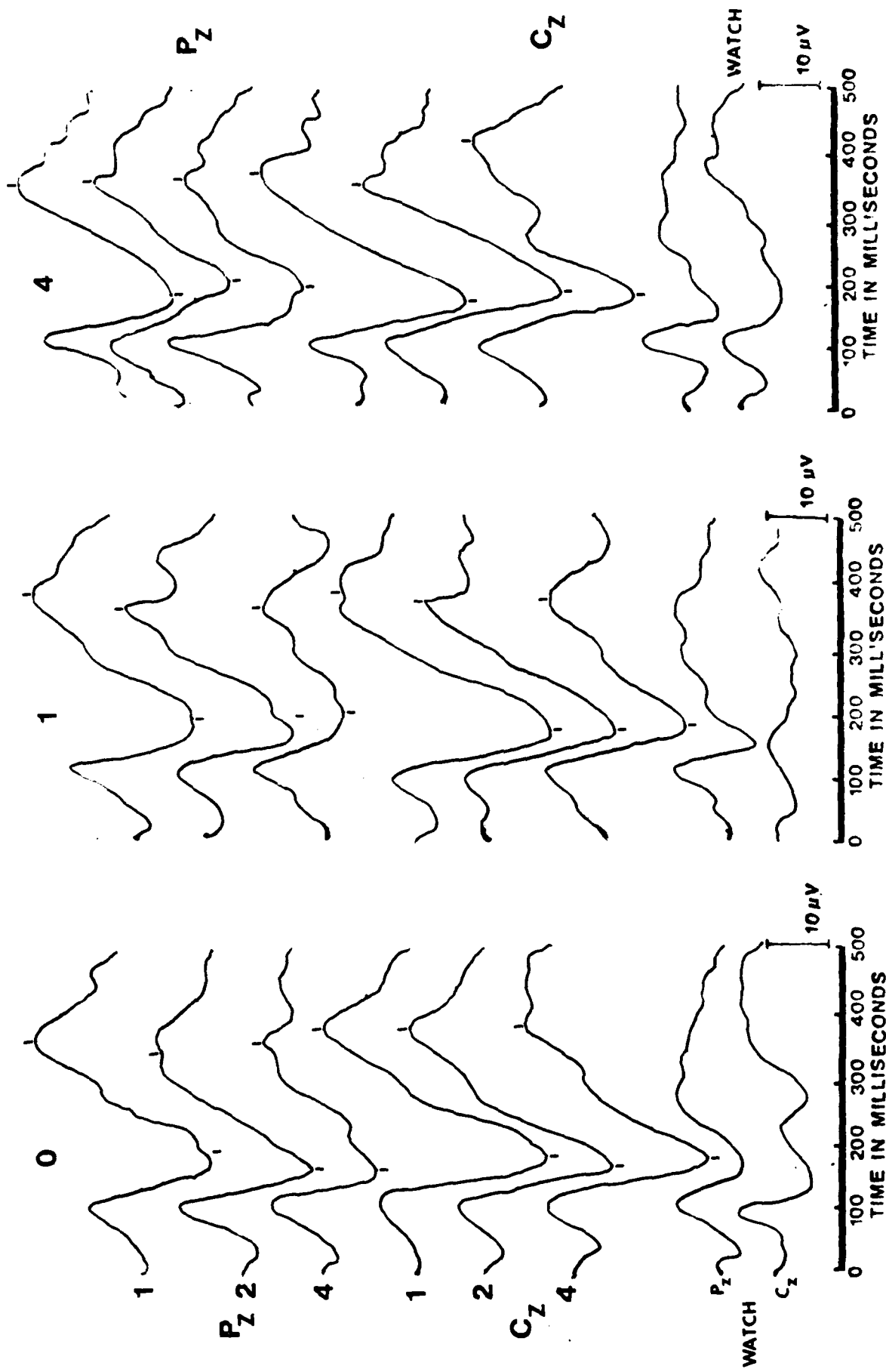


Figure 1 - Visual ERPs of S.A. recorded from P<sub>z</sub> and C<sub>z</sub> under task and watch conditions. Numbers at top indicate light intensity; numbers at left side indicate set size. Negativity is downward.

Data analysis was accomplished by computing the mean amplitude ( $\mu V$ ) and latencies (msec) from the ERP traces. Mean P3 amplitudes and P3 latencies are shown in Table 1 under the nine experimental conditions for  $C_z$  and  $P_z$ .

Analyses of Parietal Responses ( $P_z$ ): The latency data in Table 1 were subjected to a three-way ANOVA in which subjects, light intensity and memory set size were treated as main effects. The P3 latency analysis revealed significant effects for subjects,  $F=6.06$  (26/52),  $p < .01$ , the F ratio for set size was 2.63 (2/52),  $p > .05$ . However, when examined more closely, it was found that set size had an effect in the zero light condition, i.e., P3 latency was 388 msec with set size four vs 366 msec for set size one ( $t=2.53$ , 23 df,  $p < .01$ ). The P3 latency means for set sizes two and four were 373 and 388 msec, respectively ( $t=2.05$ , 26 df,  $p < .05$ ). Finally, the set size one and two yield a  $t=1.81$ , 26 df,  $p < .05$ . Under light intensities one and four, a P3 latency set size effect did not occur.

The parietal P3 amplitude analyses indicated subject,  $F=15.87$  (26/52),  $p < .01$ ; and set,  $F=21.52$  (2/52),  $p < .01$  effects. The set size differences indicated the largest amplitude ERP, with set size one (23.5  $\mu V$ ), with two next (21.1  $\mu V$ ) and four last (18.2  $\mu V$ ). The Newman-Keuls test showed a significant ( $p < .01$ ) difference only between set sizes one and four.

Analyses of Vertex (Central) Responses ( $C_z$ ) Latency: Latencies for P3 varied as a function of subjects,  $F=6.06$  (26/52),  $p < .01$  and set size,  $F=3.57$  (2/52),  $p < .01$ . The mean P3 latencies were 373, 379 and 385 msec, for sizes one, two and four, respectively. When compared for significance using the Newman-Keuls technique, set sizes one, two, and four were found to be significantly different from each other ( $p < .05$  for one vs two and two vs four, and  $p < .01$  for one vs four). To allow consistency with

TABLE I

Mean Latency (msec) and Amplitude (uV) for the Major ERP  
Component P3 for All Subjects, Placements  
and the Nine Experimental Conditions (N=27)

Conditions	Scalp Locations			
	----- P <sub>z</sub> -----		----- P <sub>z</sub> -----	
	P3 Latency	P3 Amplitude	P3 Latency	P3 Amplitude
NO LIGHT - Set Size 1	366	23.1	367	21.1
NO LIGHT - Set Size 2	373	21.8	375	19.3
NO LIGHT - Set Size 4	388	20.1	389	17.6
INTENSITY 1 - Set Size 1	371	23.8	375	21.6
INTENSITY 1 - Set Size 2	384	20.4	380	17.8
INTENSITY 1 - Set Size 4	379	17.8	385	14.9
INTENSITY 4 - Set Size 1	376	23.5	377	19.5
INTENSITY 4 - Set Size 2	376	21.1	381	19.7
INTENSITY 4 - Set Size 4	377	16.7	379	14.7

analyses conducted for P3 latencies derived from  $P_z$ , t-tests for correlated data were computed for these comparisons under the zero light condition. The results were similar in that smaller set size resulted in shorter P3 latencies. For set sizes one, two and four, the mean latencies were 367, 375 and 389 msec, respectively. The t-tests showed significant differences for set sizes one vs four ( $t=2.71$ , 26 df,  $p<.01$ ) and two vs four ( $t=2.15$ , 26 df,  $p<.025$ ) but not for one vs two ( $t=1.57$ , 26 df,  $p>.05$ ).

Estimate of Variability--Parietal and Central P3 Latency Responses--

No Light: The standard deviation (SD) was computed for P3 latencies within each set size under the no light condition. For  $P_z$  responses, the SDs were 25.5, 29.5 and 45.7 msec for the one, two and four set size conditions, respectively. This indicates increasing variability in P3 response as a function of increasing set size. Variability in P3 latency responses was also found to increase as a function of increasing set size at  $C_z$ . The SDs under the no light condition were 29.9, 32.8 and 45.9 msec for set sizes one, two, and four, respectively.

Amplitude--The P3 amplitude analysis gave significant subject,  $F=10.64$  (26/52),  $p<.01$  and set effects,  $F=14.12$  (2/52),  $p<.01$ . The mean amplitudes were 20.76, 18.92 and 15.72  $\mu V$ , for set sizes one, two and four, respectively. In other words, an inverse relationship was found between P3 amplitude and set size\*. The differences between one vs two, two vs four, and one vs four were all significant at  $p<.01$  (Newman-Keuls).

Figure 2 shows mean RTs above and mean P3 latencies below for  $C_z$  and  $P_z$  as a function of set size. Also shown are the same RT and P3 data when only data for the zero light condition were plotted. The plotted data show a steeper RT slope with all light conditions (27.1 msec longer per each addition item) than with zero light (23.0 msec per each additional item).

\* There were also significant negative relationships between P3 amplitudes and reaction time for  $P_z$  ( $r_p = -.63$ ,  $p<.01$ ) and  $C_z$  ( $r_p = -.61$ ,  $p<.01$ ). (See Figures 3 and 4).



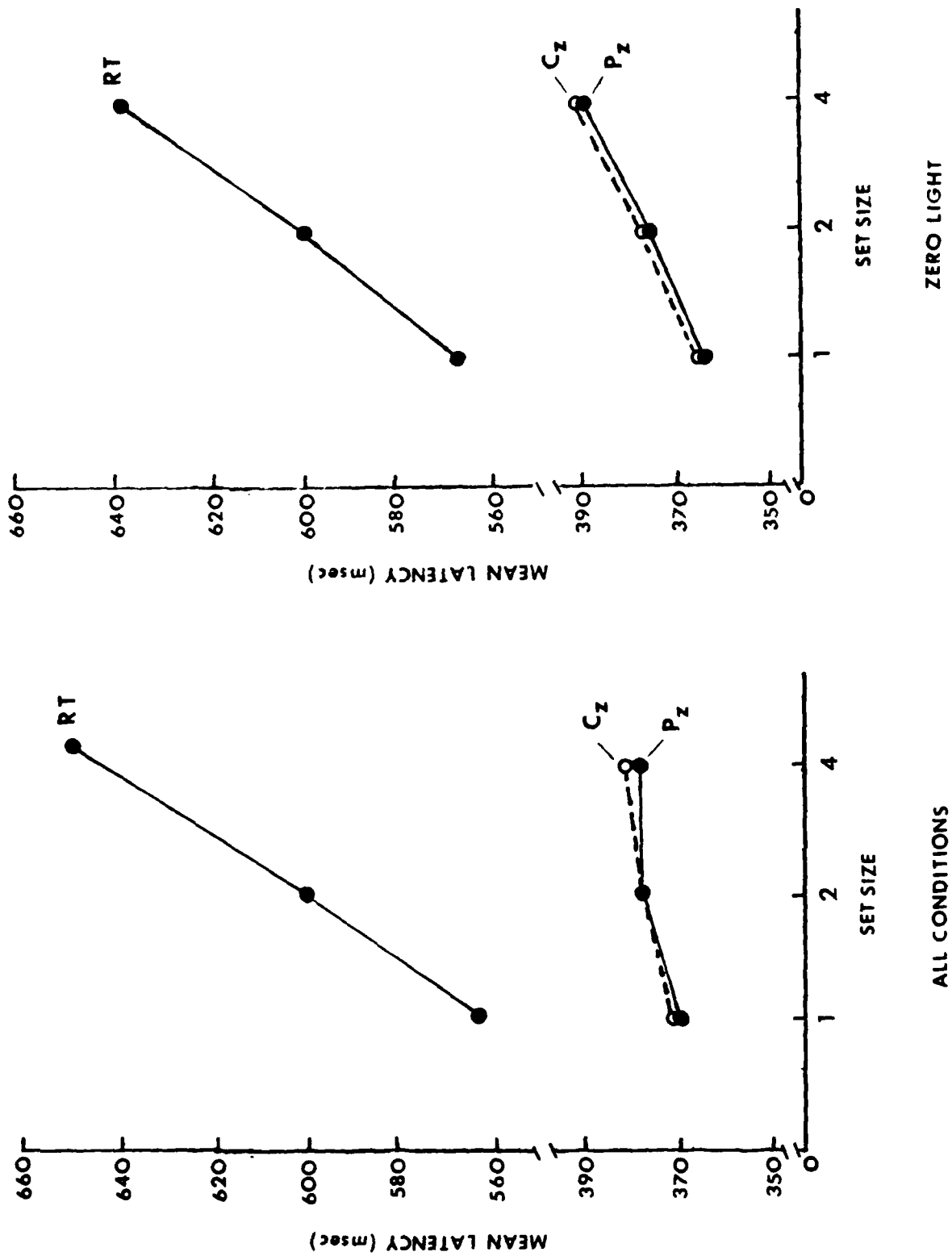


Figure 2 - Mean RT and mean P<sub>z</sub> latencies (P<sub>z</sub> and C<sub>z</sub>) as a function of set size under all light conditions and zero light (N=27).

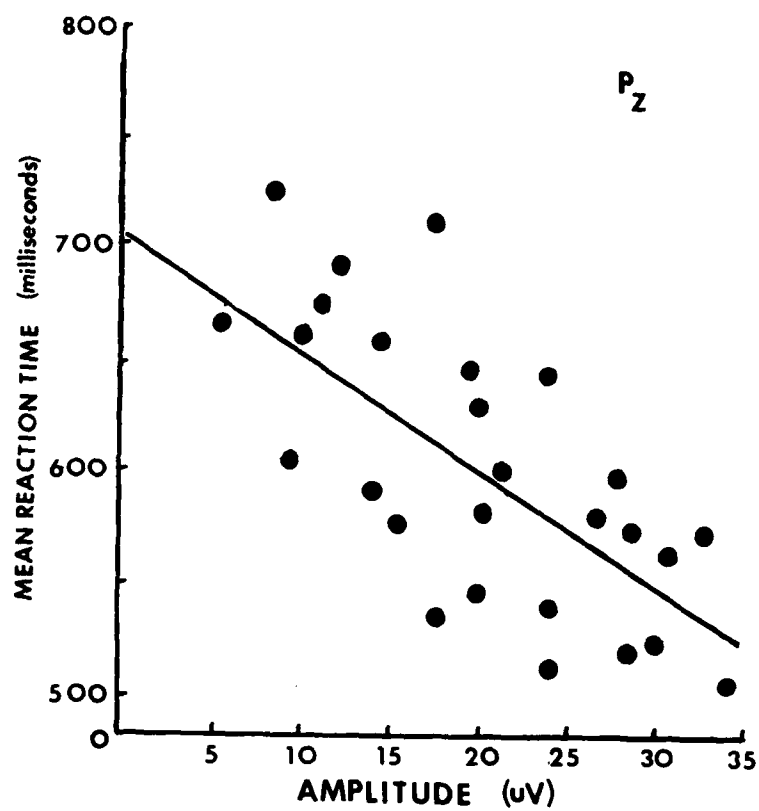


Figure 3 - Scattergram showing inverse relation between RT and P3 amplitude at P<sub>Z</sub> (N=27).

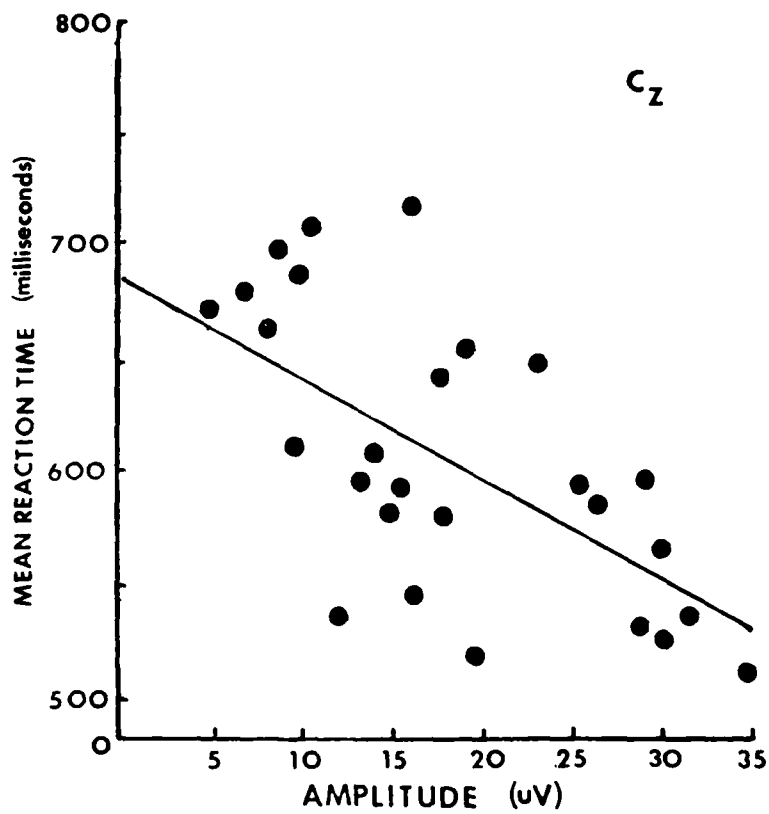


Figure 4 - Scattergram showing inverse relation between RT and P3 amplitude at  $C_z$  (N=27).

The slopes for P3 latency increases are also steeper when the means for the three light conditions are compared with zero light for  $C_z$  (4.0 msec per item vs 7.7 msec) and  $P_z$  (3.3 msec per item vs 7.3 msec with no light).

Heart Rate--Subsequent to log transformation of the HR values, a three-way ANOVA was computed in which subjects, light condition and set size were treated as main effects. The significant F ratios occurred with subjects,  $F=220.4$  (26/52),  $p<.001$  and set size,  $F=5.29$  (2/52),  $p<.01$ . For set sizes one, two and four, HR was a mean 70.4, 70.6 and 73.0 beats per minute (BPM). The Newman-Keuls tests indicated that HR was significantly higher with size four than with two or one ( $p<.01$  for both). It is interesting to note that HR increased as a function of set size. These relationships for HR, P3 amplitude and set size are shown in Figure 5. Light intensity did not significantly affect HR during the task conditions or during conditions where the subject was merely required to watch numbers appear on the screen.

Pulse Wave Velocity--A three-way ANOVA was conducted on the log-transformed values. The only significant effect was for subjects,  $F=26.16$  (26/52),  $p<.01$ .

Skin Temperature--The ANOVA on log transformed values, as with PWV, showed only a subjects effect,  $F=38.51$  (26/52),  $p<.001$ .

Electromyogram (EMG)--A similar ANOVA for EMG data yielded a subject effect,  $F=62.25$  (26/52),  $p<.01$  during the Sternberg task. When subjects were required to watch numbers on the screen, however, and were not engaged in the task, there was a significant light effect on EMG,  $F=3.47$  (2/52),  $p<.05$ .

Task vs Watch: The various physiological responses recorded during the task were also compared with those recorded during the "watch" periods.

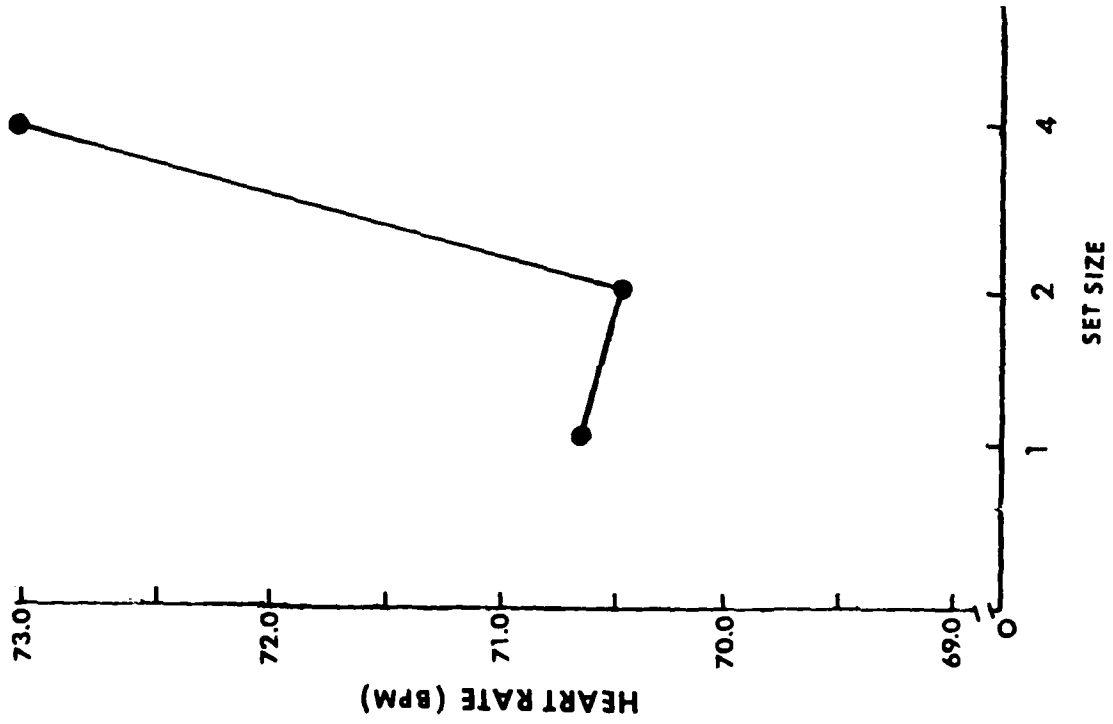
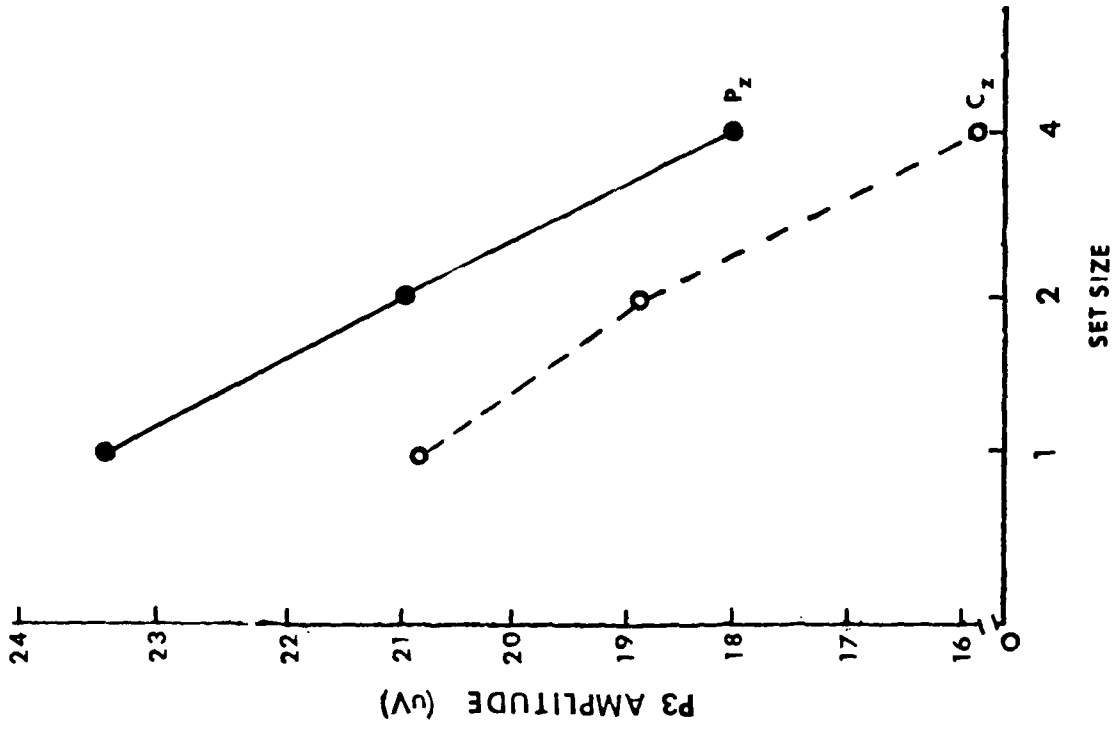


Figure 5 - Mean heart rate as a function of set size and mean P3 amplitude (Pz and Cz) also as a function of set size.

A three-way ANOVA was used in which subjects, task (i.e., task vs watch), and light conditions served as main effects.

Parietal Responses ( $P_z$ )--The P3 latency component showed a significant task effect ( $F=17.30$  (1/26),  $p<.01$ ). This indicated that, overall, P3 latency responses recorded during the task were significantly longer than responses recorded during the watch periods. The mean difference was 29 msec (task=377 msec, across set size, i.e., #1=371, #2=382, #4=382 vs watch=348 msec). With respect to P3 amplitudes, significant effects were found for subjects,  $F=4.10$  (26/26),  $p<.01$  and task,  $F=95.37$  (1/26),  $p<.01$ . The significant task effect reflected the finding that amplitudes were larger during the task as compared to amplitudes during watch (task=21.1 uV vs watch=11.8 uV).

Central Responses ( $C_z$ )--As was the case with P3 latencies recorded from  $P_z$ , the ANOVA on the P3 latency data revealed a significant task effect as well, with  $F=15.70$  (1/26),  $p<.01$ . This indicated that P3 latency responses during the task were longer than responses during the watch periods. Mean P3 latencies recorded during the task were 379 msec, across set size, i.e., #1=373, #2=379, #3=385 vs 350 msec during the watch periods, a mean difference of 29 msec. Conversely, the ANOVA conducted on the P3 data revealed that amplitudes recorded during the task were significantly larger than amplitudes with the watch,  $F=32.24$  (1/26),  $p<.01$ . The mean amplitudes in uV were 18.6 and 10.6 for task and watch, respectively, a difference of 8 uV.

The concept of LIV was addressed by computing each subject's percent change in each physiological measure (except ERPs) from baseline to task conditions. The baseline measures were ranked from low to high and a median value selected. Subject's percent change from baseline was examined

with respect to whether the measure was below or above the median. In addition, a group average percent change from baseline was computed for the below and above groups separately.

The median baseline HR was 72.4 BPM. An examination of percent changes from baseline for subjects in the below median group (i.e., baseline HR below 72.4) revealed that 6 of 13 subjects had increases from baseline to task. The group, on the average, showed a percent change increase of 1.5%. With respect to the above median group, 5 of 13 subjects showed increases from baseline to task, and as a group, showed an average percent decrease of .9%.

The median baseline PWV was 33.4 mm/cm. With regard to percent change from baseline to task conditions, an equal number of subjects in each group showed decreases, i.e., 6 of 13 for the below median group and 6 of 13 for the above. The group average percent change was 3.6% (increase) and -2.2% (decrease) for the below and above median group, respectively.

A ranking of subjects' baseline EMG measures yielded a median of 1.67 uV. A total of 12 of the 13 subjects from the below median baseline group showed an increase in EMG activity during the task. The group average percent increase was 30%. Although 8 of 13 subjects from the above median group showed increases as well, the magnitude of the average percent increase was smaller--17.6%.

For ST, the median was 83.41 degrees Fahrenheit. Nine subjects in the below median group showed decreases in percent change from baseline to task, while 12 of 13 subjects in the above median group showed decreases. When the below and above median subjects are considered in separate groups, the average percent change was -.5% and -3.3%, respectively.

Type A vs Type B: Analyses of the Jenkins Activity Survey indicated that 7 subjects scored high (i.e., 75th percentile and above) on the type A scale, while 6 subjects scored low (25th percentile and below). These subjects were considered type A (N=7) and type B (N=6) groups respectively and compared with each other with respect to the effect of the high intensity light (intensity four) on performance (reaction time).

Reaction time responses during the zero light condition were compared to those made during the highest intensity condition. For the type A group, 4 out of the 7 subjects showed improvement (i.e., faster RTs) with the intensity four condition as compared to the zero light condition (on the average, 21 msec). When the two groups' RT responses under the intensity four condition was compared, the type B group showed better performance (569 msec) than the type A group (595 msec). A t-test for uncorrelated data, however, indicated that this difference was non-significant ( $t=.61$ , 11 df,  $p>.05$ ).

The type A (N=7) and type B (N=6) groups were also compared with respect to the physiological measures recorded during the task and during the baseline period. The visual ERPs (i.e., N150, P3 latencies; P3 amplitude) failed to distinguish the type A from the type B group, i.e., there were no significant differences in response between these two groups for any of the major ERP components (t-test, uncorrelated data: type A vs type B for N150 and P3 latency; P3 amplitude,  $p>.05$  for all comparisons). It was found, however, that type A subjects had significantly lower skin temperature than type B subjects. This was found to be the case during baseline (type A=79.88° vs type B=88.58°,  $t=3.18$ , 11 df,  $p<.01$ ), watch (type A=78.29° vs type B=85.53°,  $t=2.69$ , 11 df,  $p<.05$ ) and during the task (type A=78.11° vs type B=85.69°,  $t=2.87$ , 11 df,  $p<.02$ ). While



there were no differences between type A and type B subjects for the other physiological measures (i.e., HR, PWV, EMG) the type A subjects showed a significant increase in EMG activity from baseline to task conditions (baseline=2.13 uV vs task=3.82 uV,  $t=2.03$ , 6 df,  $p<.05$ ). The type B individuals did not manifest this increase (baseline=3.91 uV vs task=3.99 uV,  $t=.31$ , 5 df,  $p>.05$ ). The average increase for the type A group was 1.69 uV and sharply contrasts with the small non-significant increase of .07 uV for the type B group. Type B subjects did show significant decreases in ST from baseline to task conditions ( $t=2.49$ , 5 df,  $p<.05$ ) while the type A subjects did not ( $t=1.31$ , 6 df,  $p>.05$ ).

#### DISCUSSION

The finding that RT latency increased as a function of set size with no light stimulation was similar to previous findings of Adam and Collins (1978), Ford et al. (1979), and Gomer et al. (1976). The observed increases in P3 latency with larger set sizes occurred at both the parietal and central recording areas. This longer P3 latency response with increased processing demand is likely related to the greater stimulus evaluation time required with a more difficult task as hypothesized by Donchin (1978) and McCarthy and Donchin (1981). The fact that the expected P3 latency and set size effect did not occur with light intensities one and four suggests that the light stimulation had a disrupting effect on P3 latency. While the effects were in the direction of increased P3 latency with larger set size, the differences were not significant. The unpredictable appearance of the light may have altered the P3 by producing a sensory ERP at a point in time which was close to the occurrence of P3.

The interesting finding that P3 amplitudes decreased with an increase in set size was also observed at both recording sites. This finding had previously been reported by Gomer et al. (1976) for P3 response to negative set items at the central recording area. We believe that the more difficult task of processing larger set sizes led to a greater amount of response uncertainty on the part of subjects. This greater degree of "equivocation" (Ruchkin and Sutton, 1978; Sutton, 1979) results in a lowered P3 amplitude for larger set sizes. In the Ruchkin and Sutton (1978) study, equivocation was induced through temporal uncertainty and they noted that the emitted P3 (i.e., P3 to expected but undelivered stimulus) was of lower amplitude and broader duration than the evoked P3. They suggested that this may be due to the more imprecise timing and greater uncertainty that occurs when a subject is estimating the time of stimulus occurrence, i.e., variations in time estimation could lead to variation in the latencies of the emitted P3, thereby contributing to lower amplitude and broader duration responses. Pritchard (1981) points out that equivocation can also be produced by increasing the difficulty of the task without manipulating temporal uncertainty. For example, it appears that the lower the confidence in a perceptual task, the lower the P3 amplitude. An alternative explanation is that there was a greater amount of P3 latency variation with large set sizes and that this produced the P3 amplitude attenuation. An examination of the variability of P3 latency with the three set sizes revealed that under set size four the variability (standard deviation) among subjects was much greater than it was for sizes one and two (both  $P_z$  and  $C_z$ ).

The finding that P3 latencies from both recording sites were longer during performance of the Sternberg task than during the situation when

subjects were asked to simply watch the stimuli seems to corroborate the notion that the P3 component is delayed when cognitive demand or information processing requirements are greater, or when stimulus evaluation takes longer. In addition to longer latencies, the P3 amplitudes at both parietal and central recording sites were much larger under Sternberg task vs the watch condition. This indicates that P3 is of greater magnitude when individuals are required to perform or attend to a task compared to when lesser demands are made. This was the conclusion in a number of studies, e.g., that of Ford et al. (1976) in which P3 to an infrequent event increased in amplitude with increased attention and Hillyard et al. (1971) in which P3 was enlarged only when information was being actively processed.

Heart rate increased significantly with set size four compared to sizes one and two since increased task demands resulted in greater cardiac output. Increased cardiovascular activity has been associated by other investigators with logical, verbal cognitive processes (Campos and Johnson, 1966, 1967; Lacey, 1967). In the present experiment, the condition that produced higher HR, i.e., increased set size, also resulted in lower P3 amplitude. Might we propose a causal relationship between HR and P3 amplitude? The stimulus intake-rejection hypothesis of the Laceys' (Lacey, 1967; Lacey and Lacey, 1974) postulated a cardiovascular-brain interaction with implications for behavioral efficiency. Briefly, the Laceys' propose an inverse relationship between baroreceptor activity and brain activity, such that decreases in HR are related to attention and increased brain activity and sensitivity to stimuli (intake) allowing improved stimulus perception. On the other hand, increases in HR have been associated with decreases in brain activity and sensitivity to environmental

stimuli (rejection), thus allowing more efficient cognitive processing. In the current instance, we believe that the relation observed between HR and P3 is incidental. That is, they are not causally related to each other but, rather, both are related to a third factor (increased task demand) that influences each. While increased HR was related to meeting increased cognitive demands, the decrease in P3 amplitude occurred because the more difficult task resulted in greater uncertainty on the part of subjects performing the task, and a greater variability in the time of occurrence of P3, an important factor in the reduction of response amplitude.

Relation Between Physiological Measures and Performance: The smaller amplitude P3s associated with longer RTs indicate that P3 attenuation occurs when responses are more uncertain. Alternatively, as pointed out earlier, it could also indicate greater latency variability in P3 with increased set size, with such variability producing a decrease in P3 amplitude. No other significant correlations were found for any of the other measures (HR, EMG, ST, PWV) and RT.

Light Intensity: Variations in light intensity did not affect any of the physiological measures during the performance of the Sternberg task. This was also true under watch conditions except for EMG which was significantly higher under intensity one than with zero light. Perhaps the task engagement allowed subjects to ignore the light to a greater extent than when they were merely asked to watch numbers on the screen. Variations in light intensity did not have an effect on RT since it was essentially the same under all light conditions.

Law of Initial Values: There was a tendency for those subjects above the median baseline response for HR, EMG, and PWV to show a decrease in response level during task conditions, while those below the median tended

to show an increase. This result was in concert with what would be predicted by LIV. There was no such relationship for ST from baseline to task conditions.

Types A and B: Persons who scored high in type A behavior (N=7) had lower baseline skin temperatures than those low in type A behavior (type B, N=6). This was true during baseline, task and watch conditions. The other physiological measures did not differentiate type A and B individuals with the exception of EMG for which type As showed significant increases from baseline to task condition.

Type B individuals showed a significant decrease in skin temperature from baseline to task condition while type As did not. Given that type As had lower ST initially, the lack of ST change during the task could be explained by the LIV. That is, there was less of a chance for a decrease among type As under task conditions than there was for type Bs since the As were already at a low level, while type Bs were at relatively high ST levels allowing the possibility of a greater decrease in ST when task demand increased and the sympathetic nervous system was activated.

EXPERIMENT III -- An Investigation of Hemispheric Asymmetry in Size and Semantic Discriminations, and Related Visual ERPs<sup>1</sup>

INTRODUCTION

Cerebral hemispheric asymmetry has been extensively studied under many different experimental situations over the last decade. Examples of some studies are those dealing with unilateral brain lesioned and commissurotomized patients (Sperry, 1982; Kinsbourne, 1978) and those using visual discrimination paradigms with normal subjects, e.g., Umiltà et al., 1974; Sasanuma and Kobayashi, 1978; Koss, 1981. The concept of hemispheric asymmetry that has been developed attributes analytic, mathematical, and language related functions to the left hemisphere, and synthetic, nonverbal and visuo-spatial functions to the right.

Verbal-Analytic Tasks: Hines (1976) found superior left hemisphere visual recognition performance for familiar abstract nouns, but no left-right hemisphere recognition performance differences for familiar concrete nouns. This author replicated these findings with a larger sample (Hines, 1977). He concluded that familiar concrete nouns may be independently recognized by the right hemisphere. Jones (1980) used a signal detection paradigm to investigate the hypothesis that the left hemisphere, due to its specialization for verbal-analytic decision making, would respond more precisely than the right to changes in signal to noise ratios. The major findings confirmed that in terms of detection errors, the left hemisphere

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<sup>1</sup> This study was submitted by N. M. Juszcak in partial fulfillment of the requirements for the master's degree in psychology at Hunter College of the City University of New York.

made significantly fewer errors than the right hemisphere. Graves et al. (1981) used a lexical decision paradigm in which subjects made judgments as to whether two simultaneously presented words belonged to an emotional or non-emotional category. They found overall RVF (left hemisphere) superiority in decision accuracy scores for non-emotional words. However, they also found that right hemisphere decision accuracy scores (LVF scores) were better than the left for emotional words.

Visuo-Spatial Tasks: Fontenot and Benton (1972) had subjects discriminate the direction of lines (line orientation discrimination task) presented in LVF and RVF. Their results showed that accuracy for recognition of these line orientations was better in the LVF than RVF. White (1971), on the other hand, reported a RVF superiority for recognition of vertical, horizontal and 45 degree oblique lines. Umiltà et al. (1974) obtained interesting results that seem to shed some light on the inconsistent findings concerning discrimination of line orientation. In their first group (easy) White's results were replicated. That is, this group showed superior discrimination performance with RVF presentations. The second group (moderate) showed no visual field differences. However, the third group (difficult) showed clear LVF (right hemisphere) superiority. Umiltà and colleagues proposed that for the relatively easy task (group one) the left hemisphere predominated because these kinds of discriminations can be easily categorized and analyzed in verbal terms (analytic processing). The shift toward a right hemisphere superiority for the most difficult discriminations (group three) was attributed to the adoption of a visual matching strategy (visuo-spatial processing) necessitated by the lack of verbal codes to represent the orientation of these lines. Koss (1981) presented six subjects with lines positioned in two different orientations.

There were two stimulus conditions: vertical-oblique and oblique-oblique. For the first condition, black rectangles were oriented either 90 or 95 degrees from horizontal. In the second condition, the rectangles were oriented either 95 degrees or 100 degrees from horizontal. The subjects' task was to respond to the presentations of the 95 degree stimulus orientation. Koss found an overall right hemisphere superiority.

In summary, left-right hemispheric differences have been demonstrated in a variety of verbal and visuo-spatial tasks. The results, however, do not always confirm expectations, i.e., superior left hemisphere ability in verbal tasks and better right hemisphere performance in visuo-spatial tasks. An alternate hypothesis was advanced by Sergent (1982) who proposed that both left and right hemispheres may be equally proficient with respect to verbal/visuo-spatial or analytic/holistic processing. She suggested that in some instances hemispheric asymmetries may be due to differential sensitivities of the hemispheres to the spatial frequencies comprising the visual stimuli. For example, in one experiment, subjects were required to detect target letters flashed in left, central, and right visual fields. The letters were large (consisting of low spatial frequencies) or small (high spatial frequencies). A right hemisphere superiority (i.e., shorter reaction time responses) was found when a decision had to be made on the basis of large letters, while a left hemisphere advantage was observed when decisions were made on the basis of small letters. Sergent also argued that the inconsistent findings concerning hemispheric asymmetry may be due to the varying stimulus exposure durations used when lateralizing stimuli to the respective hemispheres. Namely, short exposure durations make available only low spatial frequencies for processing and, hence, lead to right hemisphere superiorities regardless of whether the task



requires analytic or holistic processing. On the other hand, longer stimulus durations allow for more efficient processing by the left hemisphere.

Other laterality studies have utilized ERPs and performance while subjects were engaged in a variety of verbal and visuo-spatial tasks similar to the ones previously described. An ERP component shown to be sensitive to cognitive (endogenous) processes is the P3 response, appearing between 250 and 1000 msec after stimulus presentation. It has been found to be sensitive to a variety of cognitive activities such as stimulus discriminability, decision making and stimulus probability. For example, Ford et al.(1973) showed that P3 was related to visual discrimination. Subjects were required to make discriminations in the same sensory modality (e.g., flashes of light) and between modalities (click and flashes). The stimuli were made relevant or irrelevant through instructions. These investigators found that the P3 was of high amplitude to relevant stimuli, medium size if the stimulus was relevant but in the irrelevant modality, and non-existent in the irrelevant modality. Thus, P3 reflected discriminations between and within modalities.

Another dependent variable of interest with respect to discrimination performance is that of P3 latency. Gomer et al. (1976) recorded visual ERPs (scalp location  $C_z$ ) while subjects engaged in an item recognition task (Sternberg paradigm). The major findings showed that the amplitude of a late positive component (P3) evoked by positive items was larger than amplitudes elicited by negative items, and that latency of the P3 component increased as a function of increasing set size for both positive and negative items. In addition, P3 amplitudes in response to the negative items steadily declined as positive set size increased, while amplitudes of responses to positive items were invariant across set size. More important,

the significant increase in P3 latency was correlated with increases in reaction time. These authors concluded that P3 latency reflects information processing demands, i.e., P3 latency increases as information processing takes longer to complete. Donchin (1979) suggested that P3 latency is dependent upon the time it takes a person to complete an evaluation of a stimulus. A number of studies support the stimulus evaluation time hypothesis. For example, N. Squires et al. (1977) found that P3 latency varied with discriminability of relevant stimuli in a counting task. McCarthy and Donchin (1981) demonstrated that the relationship between P3 latency and reaction time depends on the extent to which the subject's response depends on stimulus evaluation. In this study, subjects were required to identify target words under two conditions of discriminability: easy or difficult. These investigators also varied response selection by changing the compatibility between the target words and response. Their results showed that under conditions of difficult discrimination, P3 latency and reaction time were coupled, i.e., longer reaction time responses observed with difficult discriminations were associated with significant increases in P3 latency. On the other hand, the stimulus-response compatibility factor only affected reaction time. They cautioned that processes reflected by P3 do not imply stimulus evaluation, but they do suggest that stimulus evaluation must be completed before P3 occurs.

There have been a number of studies which examined the question of whether ERPs reflect left hemisphere functioning in verbal type tasks. For example, Kutas and Hillyard (1980) obtained visual ERPs while subjects silently read seven word sentences presented one word at a time. They found that ERP responses to the first six words in the sentences showed prolonged positivity (400-700 msec post-stimulus) which was larger from

over the left hemisphere than the right. Ciesielski (1982) had subjects discriminate pairs of stimuli containing the same or different visual patterns while ERPs were recorded from over the two hemispheres ( $C_3$  and  $C_4$ ;  $P_3$  and  $P_4$ ). A verbal control condition was arranged at the end of the experiment. The major finding was that the N2 (i.e., the component occurring between 180 and 290 msec post-stimulus) was larger from a right hemisphere derivation for visual patterns, while P3 (290-380 msec post-stimulus) was larger at the left hemisphere for the verbal condition.

As with the behavioral studies and left hemisphere processing, the findings concerning ERP responses and left hemisphere functioning were not consistent. Rugg and Beaumont (1978) used the ERP to investigate lateral asymmetry in the processing of letter stimuli requiring verbal analysis and non-verbal stimuli requiring spatial analysis (random patterns). While it was expected that the ERP would reflect left hemisphere processing in the letter discrimination task, the only finding was that the first positive component was of shorter latency in the right hemisphere for both letter and non-verbal stimuli. They concluded that the right hemisphere was dominant in the early stages of processing both types of stimuli.

A number of studies have reported a right hemisphere superiority in a variety of visuo-spatial tasks such as face perception and discrimination of line orientation (e.g., Hay, 1981; Koss, 1981). However, several investigators have used other "visuo-spatial" tasks and obtained conflicting results. For example, Ornstein et al. (1981) hypothesized that a simple visuo-spatial task such as whole-whole matching (i.e., matching different sizes of whole circles with a standard whole circle) would result in greater left hemisphere engagement while more complex visuo-spatial tasks such as mental rotation and part-whole matching (matching parts of a circle

with a standard whole circle) would result in greater right hemisphere involvement. They found that the whole-whole task engaged the right hemisphere more than the left, i.e., the right hemisphere showed less alpha power, relative to the left, in the task. The left hemisphere showed greater involvement (i.e., lower alpha power) in the mental rotation and part-whole matching task. These investigators explained the unexpected findings by suggesting that the task itself may not determine which hemisphere will become more involved. Thus, a complex visuo-spatial task does not necessarily lead to greater right hemisphere activity. Instead, an analytic strategy may be more appropriate for this type of task.

Andreassi and Juszcak (in press) used a standard-comparison line length discrimination task with the expectation that this type of task would engage the right hemisphere to a greater extent than the left. The instructions required that subjects report whether the second of two lines (comparison) was longer or shorter than the first line. The task was constructed so that discriminations would be easy (such as when the comparison line was longer or shorter than the standard) or difficult, i.e., standard and comparison were equal in length. Performance with LVF and RVF presentation was the same, i.e., there were no hemispheric differences. The major finding was that the difficult or ambiguous discriminations were associated with a delay in P3 latencies (positive component occurring between 300 and 400 msec post-stimulus). This delay was interpreted as a further indication of P3 latency being effected by time to evaluate a stimulus, i.e., longer evaluation time with difficult discrimination resulting in longer latency P3 responses. This conclusion was similar to those of N. Squires (1977) and McCarthy and Donchin (1981). Recall that these investigators reported that P3 latency was sensitive to processes involved in stimulus discriminability.

Andreassi and Juszcak (1983) used a line orientation discrimination task similar to the one used by Koss (1981) and failed to obtain an expected LVF superiority. Subjects discriminated two lines flashed in LVF and RVF. These authors insured that the task was sufficiently difficult (i.e., error rate of at least 20 percent in pilot and experimental trials). The performance data (percent correct responses) indicated that both left and right hemispheres were equally proficient in the task. Moreover, analyses of the major ERP components revealed no differences in amplitudes or latencies (N2-P2, N3-P3, and N2, P2, P3, respectively) with respect to hemisphere.

A literature review revealed that apparently no attempt has yet been made to relate size discrimination of geometric figures to the presumably superior visuo-spatial processing capacity of the right hemisphere. Size and areal discriminations may be considered to be right hemisphere functions, assuming that the processes involved in making such discriminations are spatial and non-verbal.

It was hypothesized that:

1. RVF (left hemisphere) discriminations of words will be superior to LVF (right hemisphere) discriminations.
2. LVF (right hemisphere) discriminations of rectangle size will be superior to RVF discriminations.
3. Visual ERP amplitudes in response to the verbal stimuli will reflect greater left hemisphere involvement in the word discrimination task, i.e., amplitudes N2-P2, N3-P3 will be larger at the left hemisphere as compared to amplitudes at the right hemisphere.
4. Visual ERP responses to rectangle size discriminations will be greater from over the right hemisphere as compared to response differentials

from the left, i.e., N2-P2 and N3-P3 amplitudes will be larger at the right hemisphere compared to the left with the requirement to make geometric discriminations.

#### METHOD

Subjects: The subjects were 18 undergraduate students (10 males and 8 females) affiliated with Baruch College of the City University of New York, ranging from 18 to 30 years of age. Right-handedness was determined by a handedness questionnaire (Annett, 1970) which asked subjects to report the preferred hand used in a variety of tasks and to indicate any familial history of handedness. None of those used in the experiment reported any personal or familial history of left-handedness. A Bausch and Lomb Orthorator was used to test subjects for binocular visual acuity and vertical and lateral phoria (normal eye muscle balance). The vertical and lateral phoria tests estimated the subject's ability to maintain focus on a fixation point.\* All subjects met the criteria of acceptable visual acuity (corrected to at least 20/25) and orthophoria, as determined by Bausch and Lomb Occupational Vision Standards.

Apparatus and Procedure: Subjects were seated in an electrically shielded, sound-attenuated, IAC chamber while the electroencephalogram (EEG) was recorded from scalp locations  $P_3$  and  $P_4$  (Ten-Twenty System, Jasper, 1958) with silver clip electrodes referenced to linked earlobes.

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\* Previous research showed that persons with abnormal eye muscle balance (strabismus) have difficulty fixating on some central fixation point and consequently may not show expected contralateral visual field effects which result when stimuli are differentially presented to left and right hemispheres (Andreassi and Juszcak, 1984).

A Beckman RM Dynograph recorded the EEG signal and the 9806 coupler set the bandpass between 0.5 and 32.0 Hz. A PDP 8/E digital computer was triggered to take EEG samples of 500 msec duration immediately following presentation of visual stimuli to subjects. The summated ERP traces were printed out via a Hewlett-Packard X-Y plotter. A Washington University eye movement monitor and a Tektronix dual-trace oscilloscope were used to monitor the subject's eye movements. Eye movement was measured by placing two Beckman biominature electrodes above and below the left eye. Artifacts produced by such movements appeared as left or right deviations from zero on the monitor and as abrupt changes from baseline on the storage oscilloscope. Trials suspected of eye movement contamination (about 10%) were discarded.

Visual stimuli were displayed on a Digital Equipment Corporation VR-14 (CRT) mounted outside the IAC chamber at a distance of 114.3 cm (45 in.). A brief persistence P24 phosphor specially installed in the VR-14 screen assured rapid stimulus decay (50 usec).

The experimental conditions consisted of three words (PARE, PEAR, PAIR) and three different sizes of a rectangle, presented for 40 msec and in the same horizontal plane. The stimuli were centered at 1 degree, 24 minutes of arc in the left visual field (LVF) and right visual field (RVF) as measured from central fixation. The specific requirements of the two tasks are detailed in the following instructions which were given to subjects before collection of data.

One of three words or one of three sizes of a rectangle will appear on the screen to the left and right of the small red neon light. Your task is to define the word after it appears and to report the size of the rectangle after it appears on the screen. There are three words that sound alike, but have different meanings, and three sizes of rectangles. When the word PARE appears, you are to say "CUT." When the

word PAIR appears, say "TWO." When the word PEAR appears, you are to say "FRUIT." With respect to the rectangles, when the smallest one appears, say "SMALL," and when the largest one appears, say "LARGE." When the medium size rectangle appears, say "MEDIUM." Give your answer out loud about one second after the word or rectangle appears.

The presentation of each word and rectangle size was randomized with the restriction that each appear in the two visual fields 10 times. For example, the word PARE might appear in the LVF followed by a medium size rectangle appearing in the RVF, and so forth. The time interval between presentations was kept at a constant 4 seconds. Thus, subjects made their decision within that 4 second time interval. With two visual fields (.50), three words (.33) and three rectangle sizes (.33), the probability of the appearance of a given stimulus in a particular location was .05 (12 experimental conditions). The words were .4 X 2.3 cm (width X height) and at the 114.3 cm viewing distance, produced a visual angle of 15 minutes by 45 minutes of arc in the vertical dimension. The height of the rectangles was equated with the height of the words. The width of the rectangles produced a visual angle of 14 minutes, 15 minutes, and 16 minutes of arc for the small, medium and large rectangles, respectively (see Figure 1). The luminous intensity of the words and rectangles was equated at 2.8 mL (Tektronix J-16 photometer).

The CAT 1000 was under program control of the experimenter so that selective EEG samples could be obtained for each word and rectangle size within each visual field. Data collection continued until there were 10 uncontaminated samples in the ERP trace for each condition.

All subjects were given practice trials before the start of actual data collection. Practice trials continued until all subjects met the criteria of 40 percent accuracy for both words and rectangles. Female



<b>P</b>	<b>P</b>	<b>P</b>			
<b>E</b>	<b>A</b>	<b>A</b>			
<b>A</b>	<b>R</b>	<b>I</b>			
<b>R</b>	<b>E</b>	<b>R</b>			




		
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Figure 1 - Schematic of the three words and rectangles used in the study. Each word and rectangle was presented in LVF and RVF. The stimuli were never presented simultaneously.

subjects required a greater number of practice trials than males to reach the 40 percent criterion for rectangles. In addition, subjects were reminded to fixate on the dim light (fixation point) at all times (.001 mV red neon light) and to avoid any head or eye movements. This was critical to ensure that all stimuli were selectively presented to the left and right hemispheres. All verbal responses were monitored via an intercom system and recorded by the experimenter. The 12 conditions were counter-balanced across subjects over a period of two days and resulted in a total of 24 ERP traces from  $P_3$  and  $P_4$  for each subject.

## RESULTS

Performance: The performance data were subject discriminations of words and rectangles and are expressed as percent correct discriminations (i.e., PARE + PEAR + PAIR/180 presentations; SMALL + MEDIUM + LARGE/180 presentations).

The combined total number of correct discriminations were used for statistical analysis. Performance analyses indicated no male-female differences in discrimination scores with either the rectangles or words. Thus, only the combined ( $N=18$ ) data are reported. The data were subjected to separate two-way analyses of variance (ANOVA) in which subjects ( $N=18$ ) and visual fields (2) served as main effects (fixed model, Winer, 1971). In addition, two-way ANOVAs (subject X field) were performed to compare subjects' discriminations of words with discriminations of rectangles across visual fields (i.e., LVF + RVF/2) and within LVF and RVF. Prior to data analysis, the raw data were log-transformed to insure conformity with the assumptions of normality of distribution and homogeneity of variance required by the ANOVA model.

Visual Field: The performance data for words reveal a two percent advantage in favor of the LVF (LVF: 71.0 vs RVF: 69.0). The two-way ANOVA (subject X field), however, indicated that the main effect of field was non-significant,  $F=3.39$  (1/36),  $p > .05$ . Thus, both left and right hemispheres were equally proficient in discriminating the words. On the other hand, left hemisphere (RVF) discriminations of the rectangles were found to be significantly better than the right (LVF),  $F=25.56$  (1/36),  $p < .01$ . RVF discrimination of rectangles was, on the average, 2.5 percent better than LVF discriminations (RVF: 59.0 vs LVF: 56.5).

Words vs Rectangles: Subjects did significantly better in their discriminations of the words as compared to their discriminations of the rectangles (12 percent difference across VF,  $F=109.79$  (1/36),  $p < .01$ ). This performance superiority was consistent within each visual field. (LVF--words: 71.7 vs rectangles: 56.5; RVF--words: 69.9 vs rectangles: 59.0). The separate two-way ANOVAs (subject X field) which examined these performance differences within each visual field were also significant: LVF:  $F=922.81$  (1/36),  $p < .01$ ; RVF:  $F=58.68$  (1/36),  $p < .01$ . Taken together, these findings suggest that both left and right hemispheres were more proficient in discriminating the words used in this experiment.

Visual ERPs: Through analysis of the visual ERP traces of each subject several major ERP components emerged. These constituted the main dependent physiological variables in the study and were identified and measured in the following way with respect to latencies and amplitudes:

Latencies--Four individual components were identified: N2, P2, N3 and P3. The N2 latency component was measured from the peak of a large negative wave appearing between 150 and 190 msec post-stimulus (over all subjects) in the 500 msec sample. The component designated P2 was measured

from a positive peak immediately following N2 and occurred between 200 and 250 msec. The second negative wave following P2 was termed N3 and was found to occur between 240 and 290 msec. This component was not considered for statistical analysis and simply served as an anchor for the N3-P3 amplitude measurement as described below. The component termed P3 was a second positive peak appearing between 300 and 400 msec post-stimulus. If the peak appeared more as a plateau, the midpoint was taken as the latency measurement.

Amplitude--Two components were analyzed with regard to amplitude. These were N2-P2 and N3-P3. For N2-P2, the measurement in microvolts ( $\mu V$ ) was measured as the vertical distance from the trough of N2 to the peak of P2. The same technique was applied to the measurement of N3-P3, i.e., the vertical distance from N3 to P3.

Representative visual ERP traces of one subject are illustrated in Figure 2.

Data analysis was accomplished by computing the mean amplitude ( $\mu V$ ) and latencies (msec) from the ERP traces. The data were subjected to three-way ANOVAs. As was the case with the performance data, these measurements were log-transformed prior to analysis to insure conformity with assumptions for ANOVA. A fixed model was used in which subjects (18), conditions (12) and placements (2) and their interactions were examined.

N2-P2 Amplitude--A significant effect was obtained in the condition X placement interaction ( $F=4.14$  (11/432),  $p<.01$ ). The Newman-Keuls test revealed that for the  $P_3$  scalp location, N2-P2 amplitudes in response to the words and rectangles presented in the RVF were significantly larger than responses to the words presented in the LVF ( $p<.05$  for all comparisons). When comparing responses to each word and each rectangle within the  $P_3$  scalp location, there were no significant differences, indicating that

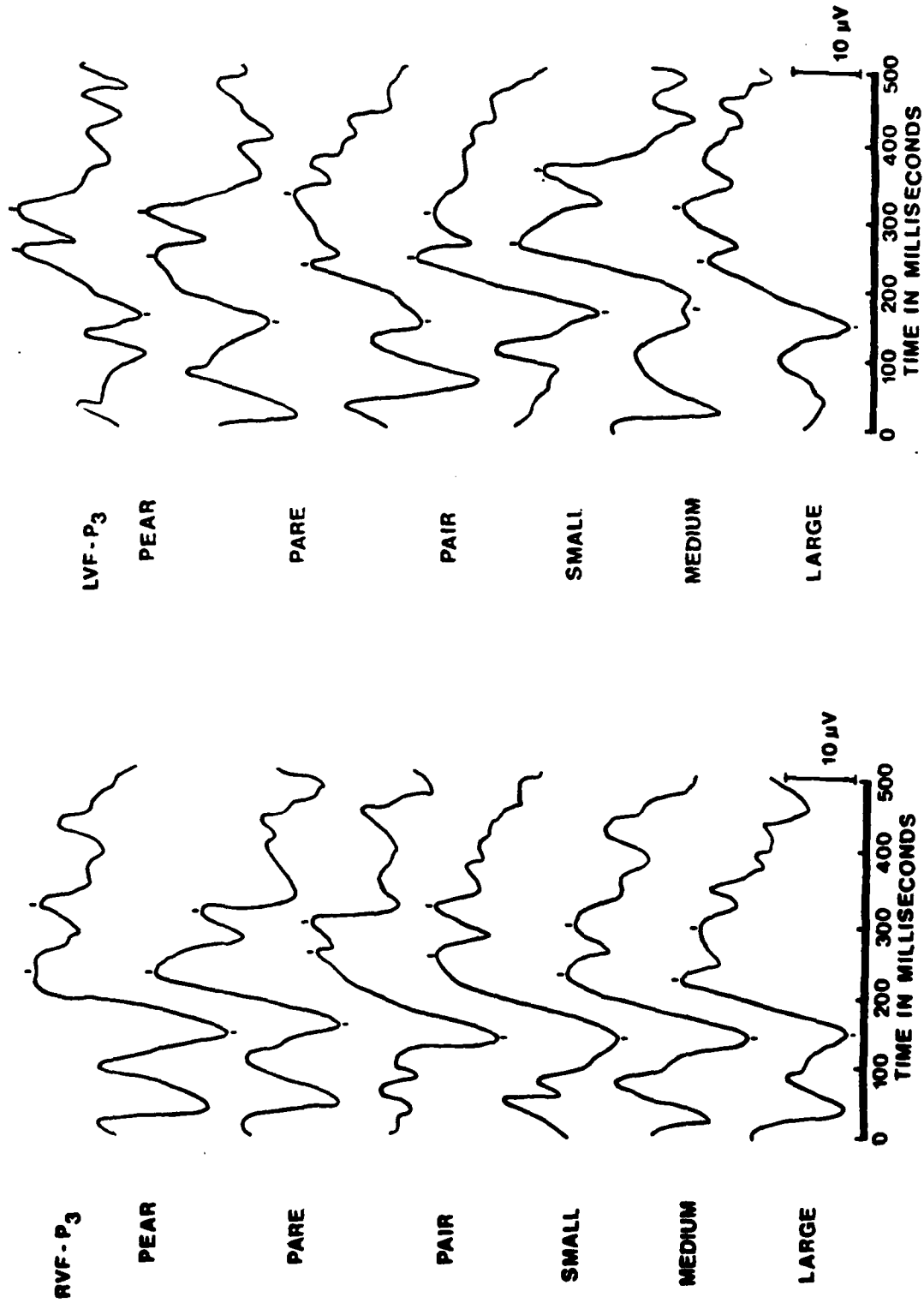


Figure 2 - Visual ERPs of subject G.A. recorded from  $P_3$  (left hemisphere) for LVF and RVF presentations. The small vertical bars indicate N2-P2 and P3 components respectively. Negativity is downward.

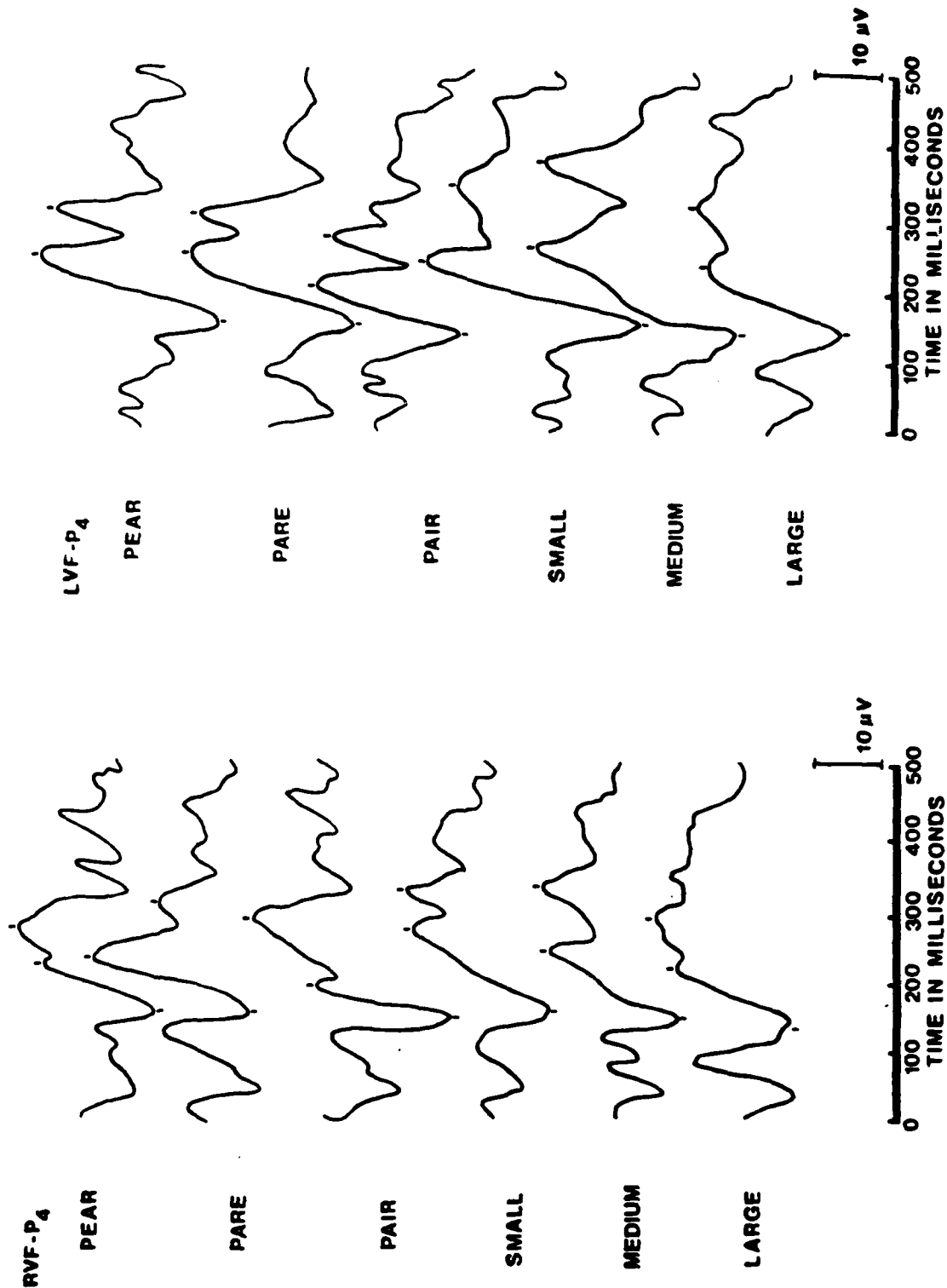


Figure 2 - Visual ERPs of subject G.A. recorded from P<sub>4</sub> (right hemisphere) for LVF and RVF presentations. The small vertical bars indicate N2-P2 and P3 components respectively. Negativity is downward.

the left hemisphere did not show differential response between words or between words and rectangles. With regard to amplitudes recorded from the  $P_4$  scalp location (right hemisphere), again, significant differences were obtained for the visual field comparison (e.g., LVF SMALL was larger than RVF SMALL, MEDIUM, LARGE,  $p < .05$  for all), but no right hemisphere response differentials were found between rectangles or between rectangles and words ( $p > .05$ ). Thus, the only major findings with N2-P2 amplitude was the contralateral visual field effect that resulted when visual stimuli were lateralized to the primary projection hemisphere (see Figure 3).

N3-P3 Amplitude--The three-way ANOVA (subjects X conditions X placements) conducted on this measure indicated that there were no significant effects (conditions:  $F=1.15$  (11/432),  $p > .05$ ; placements:  $F=.24$  (1/432),  $p > .05$ ; conditions X placements:  $F=.48$  (11/432),  $p > .05$ ). Thus, for both  $P_3$  and  $P_4$  scalp locations, N3-P3 amplitudes did not differ as a function of the field of stimulation or as a function of the different words and rectangles.

N2 Latency--Three-way ANOVA (subjects X conditions X placements) conducted on the N2 latency data showed a significant condition X placement interaction ( $F=9.00$  (11/432),  $p < .01$ ). Thus, N2 latencies showed contralateral visual field effects (see Figure 4). Newman-Keuls tests results revealed that, for LVF presentations, latencies at the right hemisphere ( $P_4$ ) were significantly shorter than latencies at the left hemisphere ( $P_3$ ), with  $p < .01$  for all comparisons. When the Newman-Keuls tests were used to compare latencies between each word and between each rectangle within LVF and RVF, there are large (significant) latency differences (approximately 10 msec) between the left and right hemisphere (i.e., between  $P_3$  and  $P_4$ ) within a given visual field.

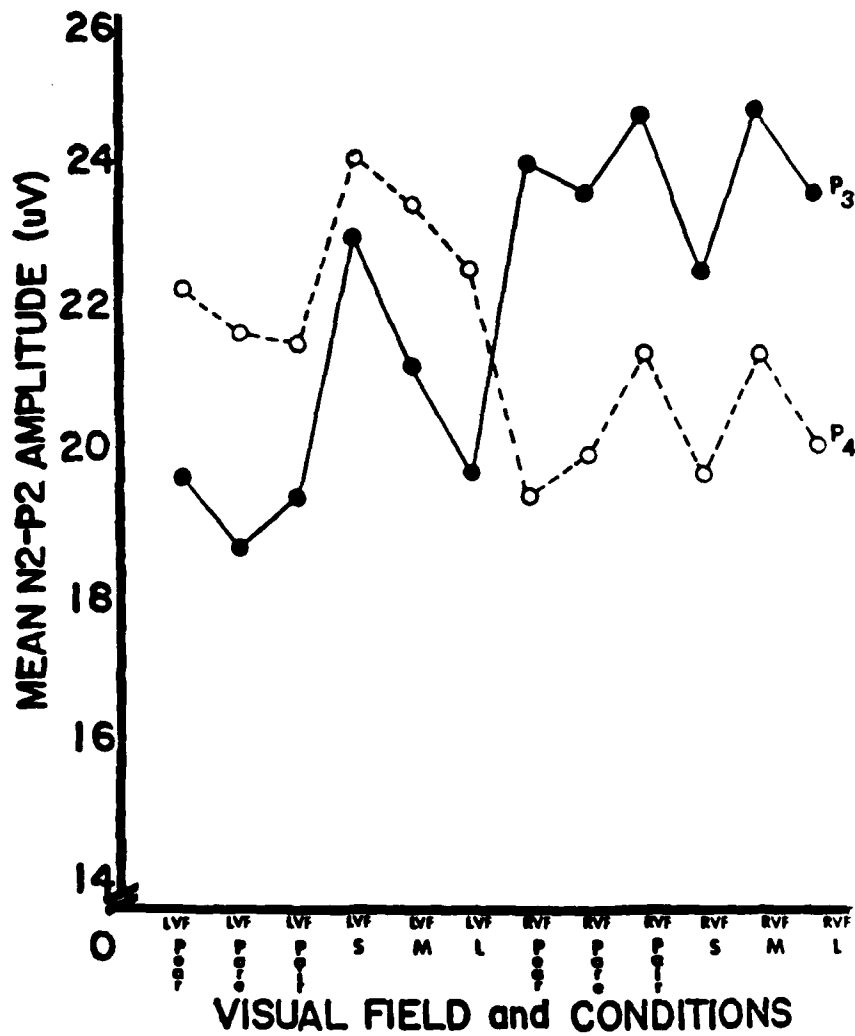


Figure 3 - Mean N2-P2 amplitudes for the 18 subjects under the conditions of the experiment. Note the larger amplitudes that occur with contralateral stimulation.



P2 Latency--The P2 latency measure showed contralateral visual field effects as well since the three-way ANOVA (subjects X conditions X placements) on this component revealed a significant condition X placement interaction,  $F=2.26$  (11/432),  $p < .01$ . However, the different words and rectangles had no effect on P2 latency responses at either scalp location (Newman-Keuls test:  $p > .05$  for all comparisons).

P3 Latency--A significant condition effect was obtained in the three-way ANOVA (subject X condition X placement) for this measure,  $F=7.00$  (11/432),  $p < .01$ . A closer examination revealed that P3 latencies in response to the SMALL and MEDIUM rectangles (LVF) were significantly longer than latencies to the word PARE (RVF). To ascertain which hemisphere was contributing to this effect, Newman-Keuls tests were conducted to compare these response differences within each scalp location. The results showed that within the right hemisphere ( $P_4$ ), P3 latencies in response to the SMALL and MEDIUM rectangles (both LVF) were significantly longer than the response to the word PARE as well ( $p < .05$ ). Thus, both left and right hemispheres produced significantly longer P3 latencies to at least one rectangle. For this reason, additional two-way ANOVAs (subject X task) were performed to compare subjects' overall P3 latency responses to words (i.e., PARE + PEAR + PAIR/3) with latency responses to the rectangles (SMALL + MEDIUM + LARGE/3) across scalp locations and within each scalp location (i.e.,  $P_3$  and  $P_4$ ) separately.

P3 Latency: Words and Rectangles--When the P3 latency responses to the words and rectangles were considered regardless of hemisphere (i.e., left and right combined), the responses to the rectangles took significantly longer than the responses to the words (task effects:  $F=8.57$  (1/36),  $p < .01$ ). This difference was, on the average, 6 msec longer for rectangles. The left

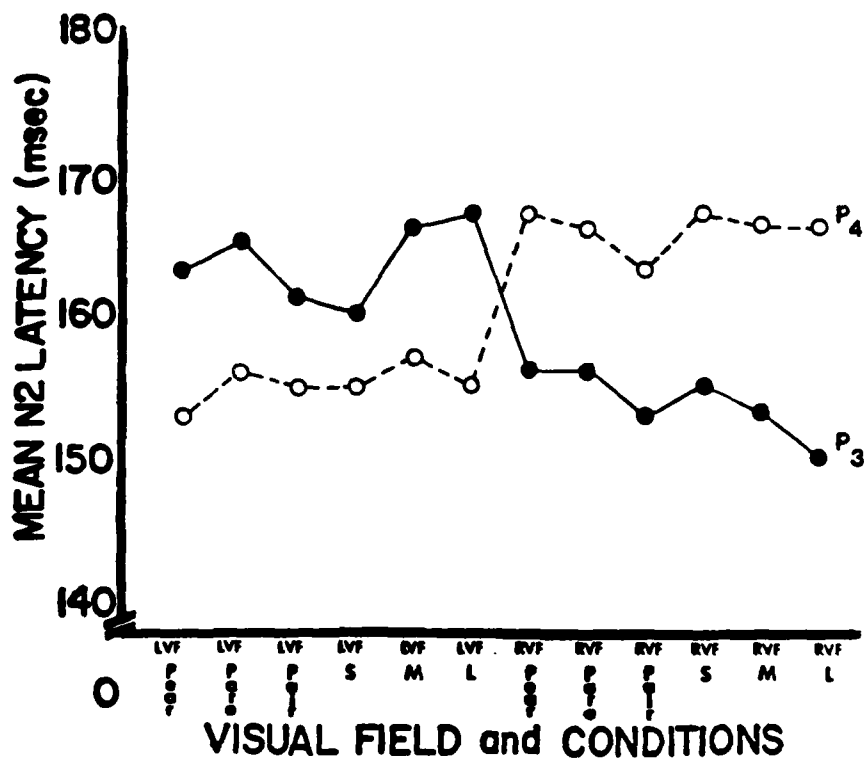


Figure 4 - Mean N2 latency for the 18 subjects under the conditions of the experiment. Note the shorter latencies that occur with contralateral stimulation.

and right hemispheres ( $P_3$  and  $P_4$ , respectively), analyzed separately, showed the same P3 latency response advantage (i.e., shorter latencies) to the words. For example, the two-way ANOVA (subject X task) performed on the P3 latency data recorded from the left hemisphere revealed a significant task effect ( $F=5.33$  (1/36),  $p < .05$ ). A significant task effect was obtained in the two-way ANOVA which made the same P3 latency response comparisons within the right hemisphere ( $F=8.89$  (1/36),  $p < .01$ ). When the P3 latency response differences between the words and rectangles are considered along with the significant performance differences discussed earlier (i.e., better discrimination performance with the words as compared to performance with the rectangles), there appeared to be a relationship between shorter P3 latencies and better discrimination performance.

#### DISCUSSION

It was expected that the left hemisphere, given its presumed superior verbal-analytic processing ability, would show better discrimination performance than the right in the verbal task. Further, this superiority would be reflected in greater left hemisphere activity (e.g., larger N2-P2 and N3-P3 amplitudes). Conversely, it was expected that right hemisphere derived ERPs would reflect an LVF superiority in the spatial (rectangle size) discrimination task in the form of greater amplitude of response. The performance and ERP data, however, failed to support these hypotheses since: 1) there were no performance and ERP differences between the hemispheres in the verbal task and 2) the left hemisphere (rather than the right) was better in the spatial task. This RVF superiority was not supported by ERPs derived from the left hemisphere, i.e., amplitudes and latencies recorded from the left

hemisphere in response to the different rectangle sizes did not differ from those obtained from the right hemisphere.

Thus, the findings in the current study contrast with those previous behavioral and electrophysiological investigations which indicated superior left hemisphere processing during tasks requiring verbal analysis (e.g., Kutas and Hillyard, 1980; Ciesielecki, 1982) and superior right hemisphere performance in tasks requiring spatial-holistic processing (e.g., Umiltà et al., 1978; Koss, 1981; Ciesielecki, 1982). The lack of laterality effects in the performance and ERP data obtained during the type of tasks used in the current study raises a question as to the degree to which the left and right hemispheres are dichotomized with respect to verbal-spatial processing ability. For example, the discrimination and ERP data collected while subjects were engaged in the verbal task seem to suggest that the right hemisphere possesses a greater capacity for verbal-analytic processing than previously thought. Sperry (1982) and other investigators (e.g., Hines, 1976, 1977) reported that the right hemisphere is capable of some language functions although this function appears to be restricted to analyzing simple concrete nouns and simple adjectives. In addition, Andreassi and Juszczak (1983) showed that both left and right hemispheres were equally proficient in discriminating simple letters and that ERPs derived from the two hemispheres were identical. However, the verbal task used in the current investigation was designed to be more demanding (error rate for all subjects was, on the average, 30 percent) and the semantic nature of the task emphasized verbal-analytic processing. That is, in order for subjects to successfully report the meaning of the word, they had to discriminate each letter, combine the letters to form a word, and, finally, undertake some type of lexical search to select the appropriate meaning. This sort

of "sequential" processing is thought to be primarily a left hemisphere function. The findings here indicate that this may not be the case.

With regard to left and right hemisphere discriminations of the rectangle sizes, the performance data suggest that the left hemisphere may be more efficient in performing this type of "visuo-spatial" task. However, this performance superiority was not reflected in left-right hemisphere visual ERP differences, as mentioned previously. The literature review indicated that size discrimination was not studied with regard to the superior visuo-spatial processing ability of the right hemisphere. Could it be that rectangle size discrimination is not a strictly visuo-spatial task? When one considers negative results obtained with regard to hemispheric specialization in other studies in which visuo-spatial tasks were used (Andreassi and Juszcak, 1981: line length; Andreassi and Juszcak, 1983: line orientation) one might also ask what criteria are used to define a task as visuo-spatial? Often, intuition is used to determine whether the processing requirements of a task are visuo-spatial. This leads to the possibility that, although a task may on the surface appear to require visuo-spatial processing, it is not known whether subjects do in fact engage in such processing. In other words, perhaps the processing requirement of the task is defined by the subject and not the task itself. Hence, subjects may engage in some analytic processing as well as visuo-spatial, depending on the individual strategy used and level of task difficulty. This notion is similar to the one proposed by Ornstein et al. (1980). They suggested that "complex" spatial tasks could be performed analytically and if analytic processing is more a capacity of the left hemisphere than the right, a complex spatial task might be processed by the left hemisphere. Recall, however, that Umiltà et al. (1974) found that "easy" visuo-spatial tasks

induced left hemisphere processing. One might ask, then, what level of task difficulty is required to induce right hemisphere visuo-spatial processing? It is doubtful that a verbal labeling strategy led to the left hemisphere superiority found in the rectangle size discrimination task since verbal labels were used in the semantic discrimination task, yet there were no visual field differences.

If left and right hemispheres are differentially sensitive to the spatial frequencies of the stimuli, as suggested by Sergent (1982), then one should expect a right hemisphere superiority to have emerged in the rectangle size discrimination task. To elaborate, Sergent (1982) indicated that relatively short stimulus exposure times (approximately 100 msec or less) may make available only low spatial frequencies for processing. Thus, the right hemisphere would predominate in tasks in which brief exposure rates are used, regardless of whether the task was analytic or holistic. However, in the current investigation, the stimuli were displayed for 40 msec and the left hemisphere was found to predominate in the rectangle size discrimination task. According to Sergent's position, the right hemisphere should have excelled. Further, the words used in the present study were presented for 40 msec and, hence, should have resulted in a right hemisphere advantage as well.

It is worth noting that females performed as well as males in their discriminations of the rectangles. This is interesting in view of the fact that some researchers have shown that males tend to do better than females in a variety of visuo-spatial tasks (e.g., Sasanuma and Kobayashi, 1978). The male performance superiority was attributed to greater lateralization of visuo-spatial functions in the right hemisphere of the male brain (Harris, 1978). An alternate hypothesis was proposed, namely, that male

performance superiority in visuo-spatial tasks may be due to culturally prescribed experiential factors. The findings obtained in this study suggest that the alternative hypothesis may be correct. Recall that females required extra practice trials with the rectangles in order to meet performance criteria. Without additional practice, females may have performed worse than males and one might have mistakenly concluded that geometric-size discriminations are another example of a task in which males excel.

The finding that subjects were better in their discriminations of the words as compared to rectangles was unequivocal (words = 70 percent accuracy vs rectangles = 58 percent). Moreover, the higher accuracy scores in favor of the words was found at both left and right hemispheres. Thus, it appears that subjects experienced greater difficulty in discriminating rectangle size. Discrimination of size seemed to have influenced P3 latency, i.e., it was found to be consistently longer (about 6 msec) when subjects made size discriminations as compared to discriminations of words. In addition, P3 latencies were longer at both left and right hemispheres (5 and 7 msec, respectively) indicating that both hemispheres were equally affected and involved in the processing. How is this relationship between P3 latency and more difficult discriminations to be interpreted? It is proposed that when subjects experienced greater difficulty in discriminating rectangle size, there was an increase in stimulus evaluation time, and this increase was reflected in a delayed P3 latency response. For example, N. Squires (1977) and McCarthy and Donchin (1981) found that P3 latencies were significantly delayed under conditions of greater task difficulty (discriminability). Andreassi and Juszcak (in press) also found that the latency of the P3 component was significantly delayed when subjects made "ambiguous" (difficult) discriminations as compared to easy discriminations. It should

be pointed out, however, that the delay in P3 latency observed with the more difficult task in the current study (i.e., rectangle size discrimination) does not necessarily reflect task difficulty nor does it reflect stimulus evaluation per se. McCarthy and Donchin (1981) pointed out that processes reflected in P3 do not imply stimulus evaluation but they do suggest that evaluation must be completed before the occurrence of P3. In any case, the present finding does suggest that the P3 latency measure may prove to be a useful objective indicator of stimulus discriminability or task difficulty.

The fact that the earlier components of the ERP (N2-P2 amplitudes and N2-P2 latencies) show contralateral visual field effects indicate that they are stimulus bound. On the other hand, P3 latency is not affected by field of stimulation, emphasizing its endogenous nature. Instead, P3 latency was influenced by the cognitive effort exerted by the subject in making a discrimination, and appears to index the completion of stimulus evaluation.



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